THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: Bryce Charles Schurr

TITLE OF THESIS: Short-term retention of pitch: Experiments of RI effects in discrimination.

DEGREE FOR WHICH THESIS WAS GRANTED: Doctor of Philosophy

YEAR THIS DEGREE GRANTED: 1976

THE UNIVERSITY OF ALBERTA

SHORT-TERM RETENTION OF PITCH:
EXPERIMENTS OF RI EFFECTS ON DISCRIMINATION.

by

Bryce Charles Schurr ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

EDMONTON, ALBERTA

FALL, 1976

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Short-term retention of pitch: Experiments of RI effects in discrimination submitted by Bryce Charles Schurr in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

Discrimination between the pitches of tones presented in a delayed comparison task is dependent upon some trace of the target (standard) stimulus being available following the retention interval. Presentation of tonal stimuli during the retention interval has been shown to interfere with pitch discrimination. Two theoretical models of pitch memory are reviewed which are contrasted by the assumptions regarding the effects of the intervening stimuli. Within the associative strength model, it is proposed that the intervening stimuli do not interfere with the memory trace of standard tone but rather provide the opportunity for pure trace decay to operate. In contrast, the assumptions of the storage-forgetting model state that stimuli occurring during the retention interval actively affect the memory trace and that the effects are a function of the similarity between the standard and intervening tones.

Two experiments are reported which examined the effects of tonal stimuli within the retention interval of 1) a forced choice, pitch discrimination task, and 2) a task requiring judgments of the difference in the pitches of the standard and a comparison tone.

The experimental paradigms of the two tasks corresponded closely. In each, a standard (S) tone was presented for a brief interval, followed by a fixed reten-

tion interval, and the presentation of a comparison (C) tone frequency. The retention interval was either free of other tonal stimuli (blank) or filled with an intervening stimulus (I tone) whose similarity to the S tone was varied systematically. In the first experiment, Ss were required to judge the S and C tones as "same" or "different." In the second experiment, judgments of the magnitude of the difference in the pitches of the S and C tones were required.

Discrimination of the difference between the S and C tones (Exp 1) was influenced by presentation of an I tone. Interference was a function of the similarity between the S and I tones but dependent upon the location of the I and C tones relative to the S tone frequency. Substantial interference was produced by placing the I and C tones in opposite directions of (contralateral to) the S tone frequency. If the I and C tones were located in the same direction from (ipsilateral to) the S tone, interference was evidenced only in certain circumstances. The source of this asymmetry of S and I tone similarity was discussed in terms of predictions of the storage-forgetting model.

Judgments of the difference in the pitches of the S and C tones (Exp 2) were influenced by the similarity between the S and I tones. However, the effects were not consistent with apparent derivations of the storage-forgetting model of

pitch memory, nor would judgments of pitch difference predict the results of Experiment 1.

Four main conclusions were drawn from the data:

1) Presentation of an I tone may interfere substantially with the discrimination between S and C tones,

2) The effects of the I tone are dependent upon not only its similarity to the S tone but relationship to the frequency of the C tone,

3) Judgments of pitch difference appear to be independent of performance in a forced choice discrimination task, and

4) The effects of the I tone upon discrimination in the forced choice paradigm are accounted for most reasonably by assuming it influences the _S_'s decision-response criteria rather than the memory trace of the S tone.

ACKNOWLEDGEMENTS

Traditionally, this section acknowledges those whose "invaluable assistance" has led to the completion of the degree's requirements. Since no one attains his degree by his efforts alone, the support, guidance and direction provided by many individuals merits more than simply recognition. Yet, the amount of effort devoted to writing acknowledgments always has surprised me. The rewards of having one's name within this section are small indeed, considering the truly private nature of these manuscripts. I shall be surprised if anyone, other than myself and the five members of my examining committee, reads this manuscript. Considering the effort which has gone into its production, I would be delighted if someone did read it, but nevertheless greatly surprised. Even if writing acknowledgments may appear to be a vacuous task, there are those to whom I am indebted greatly and, in the absence of an alternative method, I shall acknowledge my gratitude by referencing them in this section. Let me make it clear, however, that this is the least that I can do.

I am indebted to my supervisor, W.N. Runquist for his patience, quiet resolution, and continuing determination to see this task through. I appreciate the work of my committee members, Drs. D.W. Curtis, R. Fahey, S.J. Rule and J.A. Siegel. Their critical reviews and suggested

alterations of the manuscript were always appropriate and often appreciated. Dr. A.R. Dobbs deserves recognition for his services and guidance as a member of the supervisory committee. I am sorry that he was unable to be present for the examination. I would especially like to thank Dr. Rule for allowing me to use his laboratory space, and Dr. Siegel for her helpful advice on the laboratory apparatus and methodology of the experiments. Dr. T. Nilsson allowed me to use space in his laboratory and patiently awaited completion of the second experiment.

Messers P. DeGroot, P. Wong, and L. Omerzu provided the necessary expertise in designing components of the apparatus. I am indebted to Dr. P. Zelhart for providing me with the necessary financial support to continue and the frequent periods of release time to complete the research.

The role of my family is difficult to acknowledge, but none the less a critical factor in completing the degree. I thank Susan, Carie and Sean for their patience, consideration, and support throughout my graduate career. I now can assure them that this is the end.

Bryce C. Schurr

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Although ignored traditionally in theory and methodology, memory appears to play a significant role in most, if not all, psychophysical judgments. When subjects (Ss) fail to evidence 'errors' in judgment or variability in scaling stimuli, failing to consider factors such as storage, retrieval, forgetting and interference may be justified in terms of theoretical parsimony. However, when performance is less than 'perfect' the need to include factors relating to the processes of memory becomes more imperative. Psychophysical judgments usually have been considered to result from the mapping of stimuli onto an ordered psychophysical continuum corresponding to the response set. Confusions (errors) are seen more as the result of properties of the stimuli than errors within either the mapping (storage) or response (retrieval) 'systems.'

A number of individuals (e.g., Wickelgren, 1966, 1969; Massaro, 1970a, c; Deutsch, 1970, 1972a, b, 1975; W. Siegel, 1972; J. Siegel & W. Siegel, 1972) recently have questioned the validity of these assumptions. For example, the Siegels (1972) have suggested that a strong parallelism exists between the paradigms and underlying processes of the absolute judgment task and that of paired-associate

learning. Rather than considering the source of errors as within the perceptual system, they argued that confusions may reflect the influence of such factors as practice, memory load, channel capacity, decay and interference. This apparently heretical suggestion (cf., Leshowitz & Green, 1974) aligns paired-associate learning and psychophysical tasks within virtually the same theoretical framework.

Consider, for example, the delayed comparison, pitch discrimination task. In this procedure, _S_s are required to judge the pitch of two tones presented successively and separated by a brief time interval. Since the first (standard or S) tone is not physically present during the presentation of the second (comparison or C) tone, the discrimination process must rely upon some retained percept of the S tone. Hence, the discrimination task becomes a recognition-memory paradigm (W. Siegel, 1972) and shares a number of fundamental characteristics with the variety of recognition tasks involving verbal materials, assumed to assess the capacity and capabilities of the memory system.

Theories of human memory are concerned with the processes responsible for changes in the post-perceptual retention of events as a function of the length of the retention interval or events occurring within the interval (Melton, 1963). This thesis explores one area of the domain of human memory; specifically, the memory for (or retention of) the pitch of a tonal stimulus. Two alternative models of pitch memory will be presented in detail. The experi-

ments to be reported are concerned with the influence of events occurring within the retention interval as they influence the short-term memory for pitch and the adequacy of the theories in accounting for these effects.

The use of non-verbal stimuli in studies of human memory has not received the attention afforded to verbally encoded events. The basic assumption underlying this thesis is that the pitch discrimination task offers a valid alternative to traditional verbal paradigms in the study of the basic processes of human memory. It may prove to be preferable in certain circumstances.

Rehearsal of the to-be-remembered items usually has been cited as the mechanism responsible for the lack of forgetting within paradigms involving brief exposures of verbal stimuli and short retention periods; i.e., short-term memory (e.g., Brown, 1958; Broadbent, 1963, Bernbach, 1970, Atkinson & Shriffrin, 1968; Murdock, 1972). The effect of rehearsal is not as clear when the to-be-remembered items are "non-verbal" (Bernbach, 1967). Typically, instructions to rehearse (e.g., "hum") the S tone during the retention interval have not produced substantial increments in recognition performance and in some cases has led to reduced discrimination (cf., Wickelgren, 1966, 1969; Massaro, 1970a). This may result from either limitations of the speech-motor system (Thurlow, 1971) or the fact that the characteristics of tonal stimuli are principally non-verbal for most listeners (J. Siegel, 1974). When the goal of an experiment

is to isolate effects arising from length of the retention interval or events occurring within the interval, it would be advantageous to eliminate explicit or implicit rehearsal of the to-be-remembered items. The delayed comparison, pitch recognition task, then, appears to offer certain advantages over traditional verbal paradigms.

<u>Pitch and Recognition Memory</u>

The pitch attributed to an auditory stimulus is the result of a complex psychological process. While pitch is clearly related to the frequency or periodicity of the stimulus (Thurlow, 1971), it is also dependent upon intensity (sound pressure) and duration of the stimulus, as well as the presence of harmonic frequencies and characteristics of the source (e.g., timbre) (Wightman & Green, 1974), and "motivational" factors of the listener (Thurlow, 1971). A number of theories have been advanced to account for the perception of pitch. These have considered the relationship between frequency of the stimulus and the locale of activity along the basalar membrane of the ear (von Békésy, 1947), the character of cortical neural activity (Wever & Bray, 1930), and the selective analyzing system of the ear (Schouten, et al., 1962), to name a few. Although each model is capable of accounting for pitch perception within limited boundry conditions, two things are evident:

> First, the operations by which the auditory system extracts pitch from an acoustic stimulus are anything but simple; and second, we still do not

> know what those operations are. Pitch perception is still very much a mystery (Wightman & Green, 1974, p 215).

There appears, however, to be little reason to question the process or the adequacy of the theories of pitch perception within the context of the present paper. Previous literature in recognition memory and pitch discrimination typically has ignored these issues. The stimuli employed in these tasks usually are sinosoidal, pure wave forms of comparable intensity. In these cases, perceived pitch is a direct function of the periodicity of the signal. For the range of frequencies usually employed, most of the alternative models may accommodate the process of pitch perception.

Beyond this, however, is the necessity of a theory of memory to effectively explain the perceptual process. Should investigators of pitch recognition and discrimination be required to develop adequate theories of pitch perception, might we also require that those who employ verbal materials be capable of adequately explaining the perceptual processes which precede "storage" and retention; e.g., reading, letter and phoneme selection, and other attributes of those stimuli which are presumably encoded by the _S_?

"Recognition" and "discrimination" of pitch frequency are employed as interchangable terms within the literature. While experimental tasks may differ somewhat, a common

process appears to warrant this usage. With both recognition and delayed-comparison discrimination paradigms the _S_ is required to compare the presented (target) stimulus against some retained representative of a previous stimulus. The distinction between the two tasks appears to be in terms of what responses the _S_ is required to make. In a discrimination task, one is interested in when the target and the standard are "different" or distinguishable, while for a recognition task, the focus in on cases in which the two stimuli are indistinguishable. For purposes of the present paper, the terms recognition and discrimination will be employed to distinguish among the task demands of the experimental situations, but a common set of processes will be assumed for both tasks.

Time-error. Judgments of the intensity (e.g., loudness, pitch, weight, length) of a stimulus tend to be influenced by the interval between presentation of the standard and the comparison judgment. This phenomenon was initially identified as a "time-error" resulting from the retention interval (Whipple, 1901; Köhler, 1923; Pratt, 1933; cf., Andreas, 1960, and Underwood, 1966). These errors were assumed to result from a constant influence of time upon the "memory trace" of the standard stimulus (Wolfe, 1866; Pratt, 1933) and were typically "positive" in nature; i.e., resulting in augmented judgments of the comparison stimulus. A number of mechanisms were proposed to account for time-errors.

Decay of the memory image. Angell & Harwood (1899) report a study by Wolfe (1866) on the "Comparison of Clangs." The results of that study showed that "with no difference in vibrations [frequency] between the norm [standard] and [comparison] stimulus (D=0), the proportion of correct judgments was large with small time intervals, and fell off with increases in time . . . . [With the standard and comparison stimuli different, the correct responses] decreased with time, though not as much as for D=0" (Angell & Harwood, 1899, p 72). In addition, Wolfe reported a positive time-error in the judgments of his *Ss*. He concluded that "these results are due to the fact that there is a tendency to estimate the memory image, owing to its lessened intensity, as lower than an actually heard tone of the same pitch" (cited in Whipple, 1901, p 413).

Two experiments by Angell & Harwood (1899) replicated Wolfe's (1866) results. A general but irregular decrease in the percentage correct discrimination judgments over the retention intervals was noted. "As far as these results go, therefore, no law can be laid down in regard to a decrease in accuracy of the so-called tone memory for intervals up to 60 seconds [when the S and C tones are different] . . . . On the other hand, there is a very marked falling off in accuracy for judgment with increase of time [when the S and C tones are the same]" (Angell & Harwood, 1899, p 76). Partial confirmation of Wolfe's (1866) findings were evidenced.

Wolfe had proposed that the recognition (or discrimination) judgment involved a "memory image" of the S tone. "Fidelity of the memory image" (Whipple, 1901) was assumed to decrease exponentially over time in a manner "similar to Ebbinghaus' law for the forgetting of nonsense syllables" (Angell & Harwood, 1899). Similar to the proposals of latter day decay theorists (e.g., Brown, 1958; Peterson & Peterson, 1959; Norman & Wickelgren, 1965; Wickelgren, 1966, 1969), recognition was impaired by the weakening trace of the S tone. Angell & Harwood (1899), however, suggested that Wolfe's assumption of a memory image was not clearly evident from recognition data. They interpreted their results as representing the effect of "a marked difference in method of judging" (p 76) as a function of the retention interval, rather than the effects of time upon a decaying memory image of the S tone.

Similar conclusions were drawn by Whipple (1901). In one experiment (Part I, pp 416-446), Ss were instructed to attend closely to the "image" of the S tone throughout the retention period (from 2- to 60-sec). This usually resulted in the incorporation of "auxillary memory aids; [the S] visualizes the instrument, contracts his throat with incipient humming, and exhibits all those muscular phenomena which characterize active attention [rehearsal] . . . . Despite these effects attention must wain, and with attention, the [auditory] image" (Whipple, 1901, p 444). Even with the aid of "rehearsal," a general decrease in

accuracy was noted over the increasing retention intervals; most notably when the S and C tones were identical. The most frequent error was in judging different tones as equal, and the frequency of this judgment increased with length of the retention period.

In another experiment (Part II, Series IV), Ss were "distracted" from rehearsal by attending to the images of particular odors. Introspective reports of the effectiveness of the distraction task were compared against the discrimination judgments. More errors were evidenced if the S reported no image of the S tone during the retention period, but reinstatement of the image during presentation of the C tone "is of little avail for the purposes of comparison" (Whipple, 1901, p 456). While the image of the S tone may become less available to conscious rehearsal over time, "this decline or loss of the auditory image does not necessarily imply a corresponding decline or loss of various supplementary features which played a part in the [discrimination process]" (p 444).

It is somewhat interesting that, although Whipple's Ss were instructed to rehearse the S tone, they rarely reported using its image in the discrimination judgment. Instead, they reported the use of "visual-spatial" relations between the tones, familiarity, or a "complex 'something' which stands for 'high' and 'low' [pitch]" (Whipple, 1901, p 445). While both Angell & Harwood's (1899) and Whipple's (1901) experiments produced evidence which was consistent with

Wolfe's (1866) conclusion regarding the decay function of the S tone trace, there was some doubt that the "memory image" of the S tone was crucial for the discrimination judgment. Given this, it is rather surprising to see the maintenance of image-decay interpretations through subsequent interpretations of time-error.

Assimilation-interference. Köhler (1923) subsequently reviewed the evidence of "imageless" discrimination and provided an alternative interpretation of the process. Simply stated, presentation of the S tone established not a memory image of the pitch of the tone, but a phenomenal impression of its attributes relative to some "standard." Through experience with a particular set of stimuli, Ss develop a scale of the range of the attributes. A tone is perceived as "high" or "low" on the basis of a standard established for phenomenal pitch (Köhler, 1938, p 270). Discrimination between the tones was assumed to be made on the basis of the "relatedness" or "transcendence" between the phenomenal impressions (Köhler, 1938, p 272), rather than in terms of a reinstatement of the memory image for the S tone. The S tone was seen as furnishing a background against which the C tone was compared; a background relative to the phenomenal standard. Time-errors in judgments were explained by a "sinking" or decay of the "background" for the comparison-judgment (Köhler, 1938) over the retention interval. In terms similar to the decaying memory image, this would supposedly lead to a positive time-error.

Lauenstein (1932) provided evidence, which on the surface contradicted Köhler's proposition, but provided some support for the role of a phenomenal background in comparative judgments. If the interval between the S and C stimuli was filled with some other stimulus of the same modality, time-error was a function of the intensity of the intervening stimulus. If the intervening stimulus was higher ("stronger") than the S stimulus, a positive time-error was noted. On the other hand, a lower ("weaker") stimulus produced negative time-error. Lauenstein (1932) concluded that the effect was not due merely to the "sinking" background trace, but "rather a process of *assimilation* going on between the trace and the neural effects of surrounding [intervening] stimuli" (Pratt, 1933, p 294).

Experiments by Pratt (1933) confirmed Lauenstein's assumptions. If the interval between S and C tones was filled with a more intense (loud) stimulus, the difference limen for loudness increased. Likewise, following presentation of a less intense intervening stimulus, the difference limen decreased. The results were completely in accord with the assimilation hypothesis. Lauenstein's hypothesis (1932) was incorrect, however, in its prediction of the effects of a blank retention interval. Judgments under these conditions did not show the greatest time-errors (assumed on the basis of assimilation to the least intense background) but, instead, were between the two other conditions. Pratt

(1933) concluded:

> The effective comparison-value of the first member of a pair of stimuli presented for judgment with respect to intensity decreases in magnitude [over the retention period], unless the impression from some secondary stimulus constitutes an integral part of the comparison field, in which case the comparison-value of the first stimulus becomes a function both of time and the magnitude of the secondary stimulus relative to the first comparison-stimulus (p 297).

Thus, in addition to some decay process, events occurring during the retention interval could interfere with the process of discrimination. Similar views were to be expressed by a number of later theorists (e.g., McGeoch, 1932; Underwood, 1957; Melton, 1963; Massaro, 1970a, b, 1971; Deutsch, 1970, 1972a, b, 1973a), although evidence in support of an interference theory for tonal stimuli was sparse and equivocal. First, very few studies have considered systematically the effects of various intervening stimuli. Second, the results of studies varying length of the retention interval have not provided clear evidence of forgetting.

Postman (1945), for example, found that increments in a blank retention interval led to an increased difference limen but did not alter the "point of subjective equality" (cf., Dember, 1965). Such evidence would support either the positions taken by Angell & Harwood (1899) and Whipple (1901), or those of Köhler (1923), Lauenstein (1932), and Pratt (1933). When the retention interval was filled with an intervening tone, Postman (1945) found no evidence of

time-error; results that are inconsistent with an assimilation hypothesis or the general propositions of interference.

Harris (1952), Bindra, Williams & Wise (1965), and Moss, Myers & Filmore (1970) noted a decline in the accuracy of discrimination as a blank retention interval was lengthened. Aiken & Lau (1966), however, found that the percentage correct discriminations were unaffected by length of the retention interval, and Irwin (1937) noted an increase in correct discrimination over the retention period. Harris (1952) has identified procedural variables which may account for these anamolous findings; in particular the use of a single standard tone frequency has been suggested as establishing conditions of an absolute judgment task (cf., W. Siegel, 1972).

Both the Bindra, et al. (1965) and Aiken & Lau (1966) studies reported evidence of increasing "false detections" (identified as a "different" response when the stimuli are identical) over increasing intervals of retention. Bindra, et al. (1965) interpreted these errors as respresentative of an alteration in the Ss judgmental process (cf., Angell & Harwood, 1899; Whipple, 1901). Specifically, Ss were assumed to be varying their decision criteria as a function of the intertone interval. A similar interpretation was considered by Aiken & Lau (1966). Moss, et al. (1970) found no evidence in support of differential response criteria ('response bias'), however, and interpreted the decline in

accuracy as representative of trace decay.

Wickelgren (1969) has failed to acknowledge the effects of intervening stimuli and has rejected suggestions of differential response criteria in favor of a trace decay model. Massaro (1970a, c) has provided evidence interpreted to indicate both trace decay over the retention period and retroactive interference effects of the intervening stimuli. Wickelgren's and Massaro's research will be considered in detail within the context of their respective models later. A number of recent studies have been devoted to "pitch memory." Of these, however, only a few deal specifically with the issues of retention and forgetting, and the retroactive effects of events during the retention interval.

Locus of Interference

While presenting an "interference" (I) tone during the interval between S and C tones appears to affect the discrimination process, it is not clear at what level the effect is evidenced. Leshowitz & Cudahy (1973), for example, have reported that presentation of a "trailing" (retroactive) I tone resulted in reduced frequency discrimination (increased "discrimination thresholds") when the S & I tones were presented to the same ear. When the I tone was presented to the opposing ear, no such decrement was noted. Massaro (1970d), however, reported two experiments (Exp III, IV) in which a "masking tone" presented to the opposing ear produced decrements in pitch discrimination. Similar effects were noted when the tones were presented binaurally

(Exp I). Since the "S-tone" was presented for a very brief interval (20 msec) and the interference effects of the "masking tone" were limited to S and I tone interstimulus intervals (ISI) below 80 msec, Massaro condluded that the "interference tone prevents or limits the perceptual processing of the image of the the test (S) tone. The results alsc support the hypothesis that the auditory image is located centrally rather than at the receptor level" (1970d, p 416). Leshowitz & Cudahy's (1973) results suggest that the locus of the effect is not central but rather attributed to peripheral mechanisms.

An additional study (Cudahy & Leshowitz, 1974, Exp I) failed to find support for the assumption of peripheral interference effects. In that study a 20-msec signal (S tone) was randomly presented to one ear, followed by a 500-msec interference tone to the opposing ear, and a comparison frequency. The difference between S and C tones was selected for each Ss so that the probability of correct discrimination in the absence of the I tone was approximently .80. Substantial reductions (approx 15%) in the proportion of correct recognitions were evidenced when the I tone was presented at least 80 msec following the offset of the S tone. In a second experiment (Cudahy & Leshowitz, 1974, Exp II) the S tone signal was always presented to the same ear and the S and C tone differences were selected so that correct discrimination was 90% in the absence of the I tone. Although not as substantial as those reported in Exp I, pre-

sentation of the I tone produced decrements in the proportion of correct discriminations.

This evidence appears to suggest that even the initial processing of pitch occurs at a more central than peripheral level. At least it is clear that interference in processing and attention may be produced by events within a "sensory channel" which is peripherally independent of that receiving the signal. Yet, the effects of interference appear to be dependent to a great extent upon the specific modality of the event.

Specificity of interference. Massaro & Kahn (1973) report a number of studies which "indicate that the perceptual process [sic] of recognition requires some central processing capacity" (p 58), and that demands for processing affect pitch recognition. In two experiments (Exp I, II) Ss, presented either a saw-tooth or sine-wave form, were required first to report the quality ("sharp," "dull") of the test stimulus and then the duration ("short," "long") of the interference stimulus. Performance was unaffected by the presentation of a light as the "masking stimulus." However, if the interference stimulus was a square-wave tone, identification of the quality of the test signal was severely reduced. Again, the effect interacted with the interstimulus interval (ISI) between the signal and I tone, with performance matching that of the light condition only at ISIs greater that 180 msec.

In two subsequent experiments effects of the

"processing load" on stimulus identification were examined. In one experiment (Exp III) Ss were required to identify the quality of the test tone, or both the quality of the signal and the duration of a coincident visual distracting stimulus. Having to identify the character of the visual stimulus had no effect upon the correct identification of the test tone. If, however, the duration of the visual stimulus was lengthened to either 100- or 160-msec (Exp IV), parallel effects were noted under both identification conditions for ISIs between 0- and 120-msec. Beyond that interval, having to attend to the visual stimulus reduced performance. The requirements placed upon the S in processing the distracting stimulus limit the time available for the processing of the test tones. Hence, identification performance is reduced, not as the result of direct interference with the auditory image, but as the result of limits in the capacity to process information.

Massaro & Kahn stress that effects of processing capacity and modality-specific interference are "located in the perception stage rather than another stage of information processing" (1973, p 57). Deutsch (1970), however, has presented data which suggest that the effects may be located well beyond that level of processing, as well. Her Ss were presented a 200-msec S tone, followed by a 5-sec retention period, and a 200-msec C tone to be judged "same" or "different" than the S tone. The retention period was filled with either a series of five additional tones or

the aural presentation of a number series. The S and C tone differences (between 16- and 29-Hz) were correctly recognized in 78% of the cases when the retention interval contained the tonal series. Performance was only slightly affected by presentation of the number series (98%) or when the Ss were required to recall the numbers (95%). The results were not a function of the Ss focusing on the recall of pitch and failing to attend to the number series. The accuracy of number recall was 75% when the Ss had to also recognize the pitch difference and 73% when the Ss had only to recall the number series.

> Thus, memory for tonal pitch is considerably disrupted by other tones. However, since the requirement to remember numbers spoken at equal loudness produces only minimal decrements in the identical pitch-recognition task, this disruption could not be due to general factors such as prevention of rehearsal, limitation in information storage capacity, or displacement in short-term memory in which all items are given equal weight (Deutsch, 1970, p 1604).

These results suggest that, at very fundamental levels of processing, interference effects are modality-specific. However, if time is provided for tonal stimuli to be processed beyond the "perceptual" level, events appearing in the same modality will lead to interference only if their processing requires facilities of the system retaining pitch. The effects of presenting tonal stimuli during intermediate-term retention intervals (Massaro, 1970a, b, c; Deutsch, 1970, 1972a, b, 1973) clearly indicate the presence of this specific effect. An interesting set of studies by

J. Siegel (1974) serves to emphasize the role of the encoding modality on effects of retroactive stimuli.

Stimulus encoding. Contrasted with others, individuals with "absolute pitch" are capable of identifying virtually any musical note without error. In addition, they are capable of making discriminations between musical notes more accurately than *S*s with comparable musical training. Yet, if the differences between S and I tone frequencies are reduced considerably, absolute pitch *S*s show no better ability to discriminate pitch than control *S*s (J. Siegel, 1972). Bachem (1954) hypothesized that absolute pitch was associated with the *S*'s ability to encode the tonal stimuli as verbal mnemonics of the musical scale rather than as "frequency representatives" along the pitch continuum. J. Siegel's study sought a test of this proposition.

In one experiment J. Siegel (1974, Exp I) provided *S*s with a 1-sec S tone, followed by a 5-sec retention interval filled with 18 tones each presented for 250 msec. The *S*s were then presented a C tone differing from the S tone by either 1/10 or 3/4 of a semitone; approx. 1- or 10-Hz, respectively. The proportion of correct discriminations of the 1/10 semitone difference failed to differ reliably between absolute pitch (.69) and control (.65) *S*s. If the S and C tones were separated by 3/4 of a semitone, however, absolute pitch *S*s correctly identified the difference in 97% of the cases, while control *S*s were able to detect the difference 84% of the time.

Two additional experiments complimented these results. In one condition (Exp II), the Ss were asked to identify an S and C tone difference of 1/10 semitone following a retention interval lasting 5-, 10- or 15-sec. In the other condition (Exp III), the difference between the S and C tones was one semitone. For both experiments the retention interval was filled with successive 250 msec tones. As the retention interval was increased, discrimination under the 1/10 semitone condition decreased in a parallel fashion for both Ss with absolute pitch and control Ss. When the difference between the S and C tones was one semitone, the absolute pitch Ss were capable of correctly identifying the difference after a 15-sec retention period in 92% of the cases. On the other hand, performance of the control Ss was 86% correct discriminations at the shortest retention interval and dropped to 70% for the 15-sec interval.

> The processing of information by Ss with absolute pitch appears similar to the way in which most of us encode complex verbal material. Presentation of the stimulus results in the formation of a raw sensory trace from which information is lost within a few seconds, unless the S is able to recode it and rehearse it verbally . . . . For most of us, stimuli drawn from the sensory continua , such a pitch or loudness, have virtually no reliable, easily rehearsable associations. For this reason these materials (are) . . . subject to the rapid forgetting that is typical of the sensory mode (J. Siegel, 1974, pp 42 - 43).

The "specificity of interference" effects (Deutsch, 1970), however, would seem to imply that pitch is not retained in the "simple sensory continua" proposed by

J. Siegel (1974). If J. Siegel were correct, aural presentation of any intervening material should interfere with the retention of pitch. But Deutsch's (1970) data are inconsistent with this predicition. What J. Siegel's (1974) data may indicate is that the type of processing performed upon sensory events affects the ability of the Ss to avoid the potentially interfering effects of the intervening stimuli. The fact that an aurally presented series of numbers failed to interfere with pitch recognition (Deutsch, 1970) may reflect the differential processing afforded verbal and non-verbal units. Processing and retaining the number sequence fails to influence the retention of pitch simply due to the fact that, except at the initial stages of identification and classification (Broadbent, 1963; Norman & Rhumelhart, 1970), verbal material is processed and retained by mechanisms which are independent of those retaining information of tonal pitch.

The preceding evidence provides a rather complex picture of pitch memory. While the decline of recognition and discrimination performance over the blank retention interval may be attributable to functions of decay, events occurring within the interval between the S and C tones may interfere with the process, as well. It is clear that the effects of the intervening stimuli are, themselves, affected by the particular character of the task, their modality and the particular abilities of the S. The issues dividing decay and interference theories of pitch memory are no less

complex than those separating the general theories of memory.

In the following sections, two recent models based on conflicting theoretical stands are reviewed in detail. The associative strength model (Wickelgren, 1969) includes the tenets of trace-decay theory and has certain characteristics in common with the earlier propositions of Wolfe (1866). Alternatively, the strength-decay model (Massaro, 1970a, c) loosely incorporates the general propositions of interference with those of decay to accouunt for the recognition process. It will be shown, in subsequent sections, that the strength-decay model leads to predictions of interference which are analogous with the propositions of an assimilation hypothesis (Lauenstein, 1932; Pratt, 1933). It would appear quite simple to couch the thrust of this thesis in the resolution of the decay _vs_ interference controversy. However, preliminary evidence which will be reviewed makes it clear that a solution is not readily available. Indeed, it is uncertain whether either of the alternative theories is appropriate, provided the available evidence. What is apparent, however, is that any model that is proposed to account for the processes of discrimination and recognition must provide a explanation of the influence of events within the retention interval. How these events influence pitch-recognition memory is the principal focus of this set of experiments.

Associative Strength Theory of Pitch Memory[1]

While lengthening the unfilled (silent or blank) interval between S and C tones may lead to reduced discrimination, introducing an interference (I) tone in the interval between S and C tones has produced consistent deficits. Moreover, discrimination is an inverse function of the length of the retention interval under this condition. Wickelgren (1966, 1969) assumed that including an I tone allowed for the uncontaminated effect of time upon retention of the memory trace.

Evidence in support of decay of the memory trace of the S tone over the retention interval was provided by Wickelgren (1966, Exp I). In this study *S*s were presented one of three S tones (800-, 820-, or 840-Hz) for 2-sec followed by a 930-Hz tone presented for 2-, 4-, or 8-sec. Comparison tones were either identical to the S tone frequency or differed by +10- or +15-Hz. Immediately following termination of the C tone, *S*s reported whether the final tone was identical to (C = S, "same") or different than the S tone (C ≠ S). In addition, *S*s rated the

---

[1]While this theory has been presented in two forms (Wickelgren, 1966, 1969), the discussion will concentrate on the latter as representing the more complete formulation.

confidence of their decision on a four-point scale.[2]

The results demonstrated that discriminability (d') was reduced as a function of the duration of the I tone for both C tone frequencies. Discrimination was better when the C tone was 15-Hz higher than the S tone, but lengthening the retention interval produced nearly equivalent effects on discrimination of both the C tones. Wickelgren assumed that an I tone at least 90 Hz above the frequency of the S tone would not interfere with the trace of the S tone (1966, p 257). Hence, reduced discriminability as a function of the length of the retention interval was attributed to the autonomous decay of the S tone trace. Evidence from this and other studies (Wickelgren, 1966, Exp. II; Wickelgren, 1969) led to the formal propositions of the associative strength theory of pitch recognition.

Linear consolidation. Presentation of a pure tone (S) is assumed to activate a frequency representation most sensitive to that frequency and adjacent representatives sensitive to similar tones along the pitch continuum. The degree of activation (strength) is a normally distributed

----

[2]Prior to Wickelgren's article discrimination was typically measured by either the frequency of correct discriminations or in terms of the difference limen. In an attempt to provide a more sensitive assessment of discrimination and to avoid the problems of response bias inherent in earlier analyses, Wickelgren (1966) incorporated an extension of the theory of signal detection (TSD) within this study. The measure of discriminaability applied was d' from TSD procedures. A full development of the arguments favoring a TSD approach in lieu of traditional measures is presented by Wickelgren (1966; Egan & Clark, 1966) and need not be reiterated here.

function over an ordered set of frequency representatives, centered on the most sensitive representative (S'). Strength of the activation gradient at any point (S'±x) is a bounded exponential function of _abs_(x) and the duration of the tone (t_1). Formally:

[1] $$s[x]t_1 = \alpha[x]\cdot[1-\exp(-\theta t_1)],$$

where $s[x]\cdot t_1$ represents the strength of a frequency representative for the tone S'±x, $1-\exp(-\theta t_1)$ is a bounded acquisition function over the interval t_1, and α is a consolidation parameter of the form a[exp(-kx)].[3] In words, there is a monotonic increase in the trace strength of the S tone over the time it is presented. The rate of increase at a point [S±x] along the pitch continuum is dependent upon the distance from S' and the current strength of the pitch representative.

Exponential decay. Consolidation of the memorial trace is assumed to cease with the termination of the tone and is subject to an exponential decay function over the duration of the retention interval. The _rate_ of decay is assumed to

---

[3]Those familiar with Wickelgren's (1969) model will note that the consolidation and decay functions appear in the form of a single, rather than dual, trace proposition. There are two reasons for presenting the functions in this form, aside from simplicity. First, the conclusions in favor of a dual trace consolidation are based on tenuous data indeed. Compare, for example, results within Wickelgren's section "Decay and Single- _vs_ Dual-Trace Theories", pp 31-36. Secondly, at intervals reported here and within his own experiments, Wickelgren concluded that effects of the intermediate-term trace, missing in the present formulations, were minimal. In any event, elimination of the intermediate-term trace component does not markedly alter the propositions.

be invariant with respect to $s[x]t_1$ but is bounded by the minimum $s[x]t_1 = 0$. The formal proposition of the decay function is

[2] $$B(t_2) = \exp(-\beta t_2),$$

where t_2 is the duration of the retention interval. That is, decay of the S tone trace is a negatively accelerating function of the duration of the I tone.

From Equations 1 and 2, the trace strength of a pitch representative $S'\pm x$ following a t_1-sec presentation of the S tone frequency and a retention interval lasting t_2 sec is expressed as

$$s[x](t_1,t_2) = \alpha[x]\cdot[1-\exp(-\theta t_1)]\exp(-\beta t_2).$$

However, TSD statistics do not provide a direct measure of trace strength, but are measures of discrimination or detection. That is, between conditions in which the frequency of the C tone equals that of the S tone and that in which the frequency of the C tone differs from that of the S tone, the measure of discriminability (d') is a function of the trace strength of S' and $S'\pm x$ such that

[3] $$\begin{aligned} d'(t_1,t_2) &= s[o](t_1,t_2) - s[x](t_1,t_2) \\ &= (\alpha[o] - \alpha[x])\cdot[1-\exp(-\theta t_1)]\exp(-\beta t_2) \\ &= \alpha'[x]\cdot[1-\exp(-\theta t_1)]\exp(-\beta t_2). \end{aligned}$$

Pitch-difference and familiarity. The variable d' is a function of the similarity between S and C tones. In fact, it has been regarded as a measure of the difference between the means of the S and C tone traces; S' and C', respectively (Wickelgren, 1966, 1969). One interpretation

(Wickelgren, 1969) of the recognition process involves the aspects of pitch-difference. Upon presentation of the C tone, the _S_ is assumed to form a signed difference between C', the perceived pitch of the C tone and a sampled representative of the S tone trace, presumably S'. If the difference between the two exceeds a criterion associated with C' being from within the S tone trace, the C tone is judged "different," otherwise it is accepted as the same as the S tone. Judgments of "higher" or "lower" are made on the basis of the sign of the supercriterial difference between S' and C'.

Wickelgren (1969) has argued that when "same-different" responses are required, it is not similarity (pitch-difference) between the S and C tones which enters the into the recognition process. Rather, it is the familiarity associated with the sampled S tone modulus, and the decaying trace of the S tone which is the source of the judgment.

> Retrieval (of the S tone representative) is assumed to be accomplished by the interaction of the _strength gradient_ of the S tone with the (prememorial or perceptual) _activation gradient_ of the C tone to produce a greater or lesser degree of activation of the familiarity representative . . . When the C tone activates pitches whose strength of association to the familiarity representative are in a temporary state of facilitation, there is a greater degree of activation of the familiarity representative (Wickelgren, 1969, p 54).

This rather contorted explanation _appears_ to be equivalent to the suggestion that the _S_ selects from the activation gradient established by the C tone and retrieves

a representative from the S tone's strength gradient associated with the selected C tone modulus. The recognition decision is based upon a likelihood criterion of accepting the C tone modulus as arising from a distribution equivalent to that of the S tone. In this sense, however, the judgment is based upon the strength of the S tone trace, which Wickelgren assumes to be equivalent to familiarity.

While the propositions of familiarity may be consistent with the processes involved in "same - different" judgments, they can not account for the ability of Ss to form "higher" or "lower" judgments. Familiarity is assumed to be nondirectional and noncommutative. Responding to this obvious weakness, Wickelgren (1969) has assumed that a process equivalent to the pitch-difference is incorporated in the decision of "high - low" judgments (pp 20-21). It is not clear that these assumptions grant the theory either greater power or parsimony. Evidence in support of this dual process (Exp H-S-L, pp 22-29) does not appear to *necessarily* exclude pitch-difference as the sole decision mechanism.

Moreover, pitch-difference is implicitly related to familiarity. For instance, during presentation of the C tone "...the asymptotic familiarity value approached during the acquisition period is assumed to be a monotonically decreasing function of the distance from the S tone on the pitch dimension" (Wickelgren, 1969, p 48). Since the majority of the experiments leading to the development of

the associative strength theory employ "same - different" judgments, which are equally well accounted for in terms of *either* pitch-difference or familiarity, the point is a moot one. However, acceptance of the tenets of familiarity appears to require incorporation of the attributes and processes from the pitch-difference process to account for the *S*'s behavior.

Interaction of acquisition and decay. The assumptions of the familiarity process are explicit: Discrimination or recognition is achieved through an interaction between the memorial strength gradient of the S tone and the activation gradient of the C tone. In essence, the C tone is assumed never to "enter" memory or to form either a strength or familiarity gradient. Under these assumptions the C tone can not influence the strength distribution of the S tone.

> There is very good reason for thinking this interaction does not occur. The reason is that such an interaction . . . would be deleterious for retrieval. Thus, if it is possible for the *S* to perceive the C tone and use it for retrieval, but not acquire a memory trace for it, the *S* undoubtedly does just that under conditions of the current experiments (Wickelgren, 1969, p 58).

The logic supporting this argument is that, since the C tone is never tested for retention, a memorial representative is never established. This implies, of course, that the *S*s are capable of selectively excluding any of the stimuli from entering memory. A crucial test of this assumption rests in the influence of the I tone frequency upon discrimination of the S tone.

Instructions to _Ss_ typically suggest that they ignore the events occurring between the S and C tones. If the similarity between the S and I tones influences discrimination in these situations, arguments denying an interaction between acquisition and decay can not be valid. Moreover, if presentation of the C tone leads to the acquisition of a memorial strength gradient centered about C', the assumptions of familiarity suggest a process which is equivalent to that of pitch-difference for the recognition decision.

Evidence of consolidation and decay. There is no direct way of assessing the exponential acquisition parameter [θ in Equation 1] of the associative strength theory. Not only is decay assumed to initiate immediately following the S tone, but TSD statistics are incapable of measuring strength directly. Two experiments varying duration of the S tone (Wickelgren, 1966, Exp I; Wickelgren, 1969, pp 42-43) were designed to assess the acquisition and consolidation functions. In general, increasing t_1 improved discrimination, increased d' and differential strengths in the orders of expected magnitude. While the data were noisy, no systematic deviation from expectations of the model were noted.

Wickelgren has reported several experiments varying the S and I tone duration and the difference between C and S tones. In general, the results support predictions of an exponential decay of a single memory trace for t_2 intervals

between .5- and 8-sec (Wickelgren, 1966, Exp I; Wickelgren, 1969, pp 31-33, 35-36).

Over the retention interval (t_2) decay serves to reduce the strength gradient of the S tone in the manner expressed in [2]. The net result is to cause fewer of the "members" of the strength gradient to exceed the criterion level established for the acceptance of C = S as t_2 increases. This is commonly reflected in an increased frequency of "false-detections" or "false-positive" recognitions (Bindra, Williams & Wise, 1965; Aiken & Lau, 1966). If TSD statistics are to be employed appropriately, the decision criterion, assumed to operate in recognition, must remain constant over t_2 and differences between the C and S tones. Although a variety of alternative explanations may be generated to account for the increased errors as a function of t_2 (cf., Harris, 1952; Aiken & Lau, 1966), Wickelgren must select the loss of strength position to retain the validity of the TSD analyses. Otherwise, assumptions regarding d' are confounded with shifts in the decision-response criterion or 'response bias' (Green & Swets, 1966; Egan & Clark, 1966).

Similarity of S and I tones. The decay function [2] explicitly excludes any effects of intervening events between the S and C tones. That is, the decline in memory over the retention interval is interpreted as passive decay rather than the consequence of the interfering effects of the I tone. While this is a convenient assumption when the

difference between S and I tones is great (i.e., I = S±90 Hz), it is not clear that it is warranted when the tones are more similar. Should the I tone interfere with the memory of the S tone the effects could be either one or both of two types:

> First, the I tone could be setting up a competing memory trace which in some way interferes with the retrieval of the trace for the S tone . . . Second, the I tone could be responsible for an active destruction of the trace for the S tone . . . However, in either case one would expect these interference effects to be greater the closer the I tone is to the S tone in frequency (Wickelgren, 1969, p 37).

The effects of S and I tone similarity upon discrimination were investigated in one experiment (Wickelgren, 1969, pp 37-39). In that experiment, the S tone frequency was varied between 400- and 590-Hz, C tones were equal to the S tone or S±10 Hz, and the I tones were S±15-, 20-, 40-, 100-, 200-, S+3000-, and +8000-Hz. Duration of the S and C tones was 1-sec with a filled retention interval of 2-sec. One-half of the Ss were provided instructions to attend to the I tone while the remaining Ss were instructed to rehearse the S tone during the retention interval.

The Ss rehearsing the S tone showed a slight (probably nonsignificant) improvement in recognition when compared against the non-rehearsing Ss. The data reported by Wickelgren for the I tone frequencies up to S±200 Hz are presented in Figure 1. The mean d' was calculated over

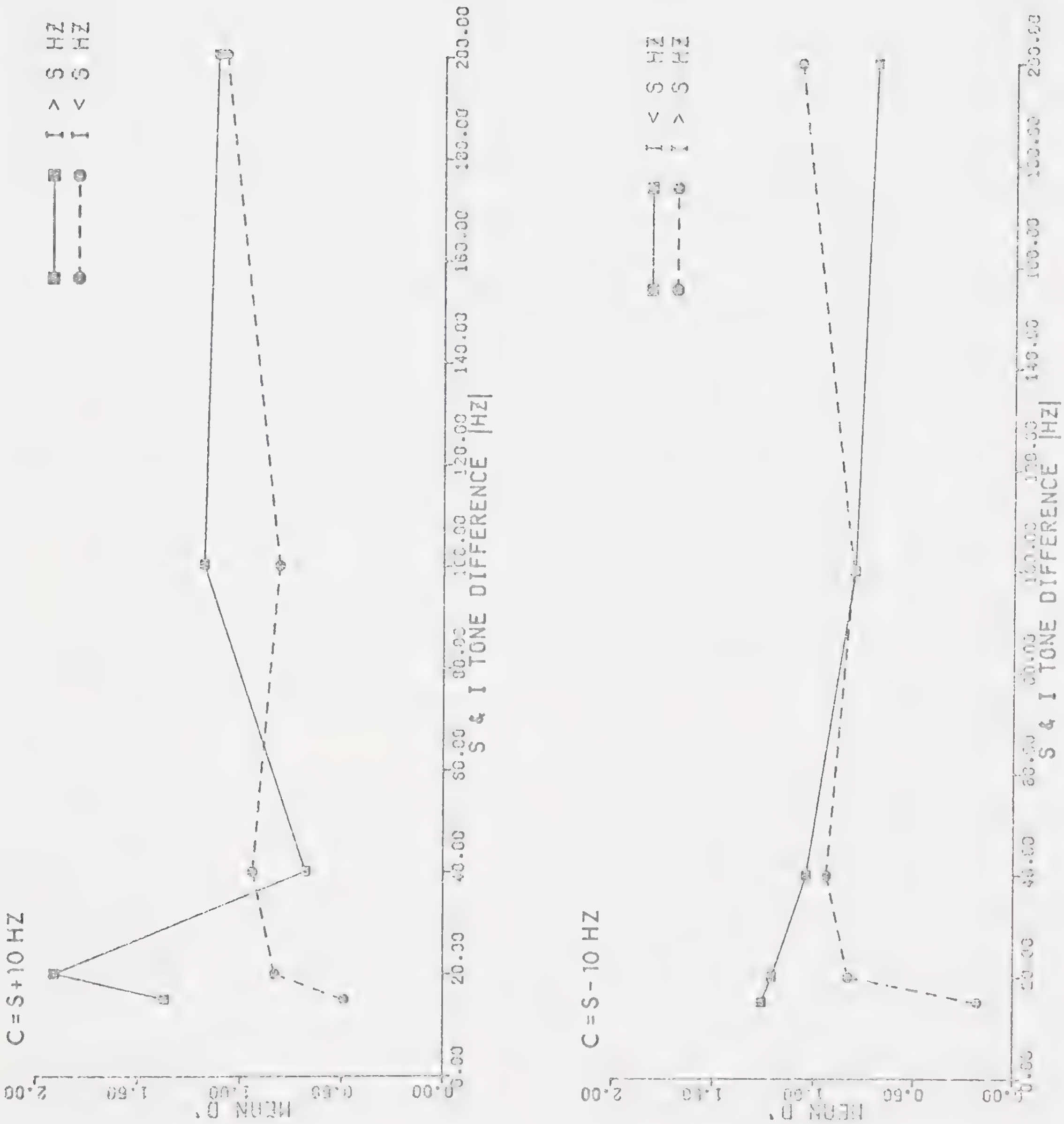

Figure 1. Mean d' as a function of the similarity between S and I tones for two S-C tone test conditions (from Wickelgren, 1969, p 38).

rehearsal conditions for each of the S-C tone differences. The conditions under which the I and C tones were on the same side of (ipsilateral to) the S tone are plotted as I > S upper panel and I < S in the in the lower panel of the Figure. Conversely, the lines labeled I < S in the upper panel and I > S in the lower panel are conditions for which the frequency of the I tone was in the opposite direction from (contralateral to) the S tone as the C tone.

> Under each instructional condition there appears to be no effect of I tone similarity on recognition memory performance at or beyond differences of 40 Hz between S and I tones. When the I tone is only 15- or 20-Hz from the S tone, there is a slight facilitation in performance when the C tone is on the same side of the S tone as I tone [i.e., I > C > S or S > C > I] and an approximately equal decrement when the C tone is on the opposite side of the S tone . . . This suggests that the decline in recognition performance with increasing delay [in previous experiments] is a temporal decay of trace strength, not a storage or retrieval interaction phenomenon (Wickelgren, 1969, p 38).

It is clear that there is little difference in performance between the I tone conditions when the frequency differences between S and I tones exceeds 100 Hz. Apparently, at these differences the I tone fails to interact with the strength gradient of the S tone, and Wickelgren's assumption regarding the previous results may be well founded. Some discussion of the effects at other S and I tone differences is warranted, however.

Under conditions in which the I and C tones were both placed above or below the S tone, there was a facilitation

in d' for S and I tone differences between 15- and 40-Hz. There is some question as to the meaning of Wickelgren's statement that an "approximately equal decrement" was evidenced over the same interval when the I tone was in the opposite direction of the S tone. Discrimination is superior under both comparison conditions when the I tone is 15- and 20-Hz different than the S tone and in the opposite direction of the C tone. These effects do not suggest that the I tone consistently produces interference as evidenced by a reduction in discrimination. They do however, suggest that the I tone has some effect upon the memory of the S tone and that the effect is, in fact, "greater the closer the I tone is to the S tone" (Wickelgren, 1969, p 37). It is clear that Wickelgren's conclusion regarding the absence of an effect of the I tone during the retention interval is not warranted when the S and I tone are of similar frequencies.

It would be advantageous to ignore the "slight deviations" from expectations of the theory under conditions of high S and I tone similarity if only to retain the efficacy of the theory in other conditions. In the light of the data provided, however, the influence of the I tone upon discrimination may prove sufficent to dismiss propositions of the theory holding to a pure decay process.

Storage-Forgetting Model of Pitch Memory

An alternative model accounting for decrements in recognition performance over the retention interval has been

proposed by Massaro (1970a, c). This model shares a number of assumptions with Wickelgren's (1969) theory but possesses features which distinguish it from the associative strength theory.

Linear consolidation and exponential decay. During presentation of the S tone, acquisition (storage) and consolidation are assumed to proceed as a bounded exponential function similar to [1]. However, while Wickelgren assumed that virtually no further consolidation of the S tone occurred following its termination, Massaro (1970c) proposed postperceptual consolidation. If the S tone is followed by a blank or unfilled retention interval, consolidation is assumed to continue at a rate equivalent to that occurring during presentation of the S tone. This assumption modifies [1] to the form:

[4] $$s[x](t_1+t_0) = \alpha[x]\cdot[1-\exp(-\theta(t_1+t_0))],$$

where t_0 is the length of the blank retention interval. This explicitly denies the action of autonomous decay during the unfilled retention interval. Consolidation, however, is assumed to be bounded by a maximum $\alpha[x]$, as proposed by Wickelgren (1969), and is proportional to the current strength.

Consolidation of the S tone is terminated by the onset of the I tone and, in the absence of consolidation, the strength of the S tone is assumed to decay exponentially over the t_2-sec filled retention interval. This proposition is diametrically opposed to Wickelgren's (1969) assumption

regarding the interaction of acquisition and decay. He assumed that presentation of the I tone did not establish a strength gradient. Massaro, on the other hand, proposes the presence of an I tone trace.

The forgetting function proposed by Massaro (1970a) modifies [2] to the form:

[5] $$B(t_2) = \exp[-\gamma(1-\exp(-\beta t_2))].$$

While decay in the associative strength model was bounded by zero, [5] yields an exponential decay function bounded by $\exp(-\gamma)$ and may approach zero only for $\gamma >> 1$. This assumption allows one to account for nonlinearity of decay without having to incorporate a dual trace (short- and intermediate-term) framework for long retention intervals (cf., Wickelgren, 1969, pp 31-33, 35-36).

The full equation of the strength of pitch representative ($S' \pm x$) presented for t_1 sec, followed by a t_0 sec blank interval and an I tone lasting t_2 sec is:

[6] $$s[x](t_1+t_0, t_2) = \alpha[x]\cdot[1-\exp(-\theta(t_1+t_0))]\exp[-\gamma(1-\exp(-\beta t_2))].$$

Trace strength recognition. As in the associative strength theory (Wickelgren, 1969), presentation of the S tone is assumed to establish a normally distributed trace strength gradient about S'. However, similar gradients are assumed to be established as the result of the presentation of the I and C tones but centered about I' and C', respectively. In addition, the acquisition of the I and C tones may interact with the established trace of the S tone

as a function of the similarity among them. The recognition process in "same - different" decisions bears some resemblence to the familiarity process of the associative strength theory.

> At presentation of the C tone, the S searches in memory for the trace of that particular C tone. If the trace strength . . . [associated that pitch] . . . exceeds some criterion k, the S will report 'same' . . . Since the consolidation of an unequal C tone ($C \neq S$) will always be less than an equal C tone ($C = S$) . . . [the trace strength of the S tone will always be greater than that of the C tone.] Therefore, noise is added at the time of the decision process so that its probabilistic nature can be predicted (Massaro, 1970c, p 153-154).

The decision (strength) criterion may vary as a function of t_1+t_0 but, as with the associative strength theory, it may not vary as a function of t_2 or the duration of the C tone (t_3) since such variations violate assumptions of TSD statistics. Since retrieval (selection) is from the trace strength gradient developed along an ordered pitch continuum, d' is more like its traditional concept of the difference between the means of "signal" and "noise" distributions than its extension to discriminability (Massaro, 1970a, p 34; Massaro, 1970c, p 154).

Although never expressly developed, pitch difference decisions appear to be more easily handled within the storage and forgetting model. Since the strength gradients are established along the same pitch continuum and discriminability is assumed to be equivalent to the difference between S' and C', signed differences in pitch are directly

obtainable. The process may occur in one of two ways. The S may form a signed difference between the selected C tone modulus and S'. Alternatively, having rejected the pitch of the C tone as equivalent to that of S', the S may then simply note the direction of the C tone from S'. The model also provides a more direct process by which the S may generate magnitude estimates of the difference between S and C tones. Such a process would be equivalent to a "signed difference" between the selected C tone and S' with the associated trace strength mapped onto a response (e.g., number or confidence) system.

Length of t_2, $t_1 \pm t_0$. Effects of the presentation of an I tone following an acquisition period of t_1+t_0-sec were examined by Massaro (1970c) in two separate experiments. In both experiments, four S tones (820-, 840-, 860-, and 880-Hz), four I tone durations (.5-, 1-, 2-, and 4-sec) and two S - C tone differences (S, S±20 Hz) were factorially combined. Frequency of the I tone and duration of the C tone were not specified. In the first experiment, the S tone was presented for 500-msec and was followed immediately by the I tone or a 500-msec silent interval preceding the I tone. In the second experiment, the duration of the S tone was shortened to 200-msec and the silent interval extended to 800-msec within appropriate conditions. Data of the two experiments were collapsed over S and C tone frequencies but analyzed separately.

According to [4], consolidation of the S tone continues

through the blank interval but is terminated by presentation of the I tone. In addition, since forgetting [5] is independent of storage, forgetting ought to occur at equivalent rates for both the acquisition period conditions.

> It is predicted that the blank interval may increase the amount of strength stored, but the proportion of memory strength lost due to consolidation of an interference tone of t_2 sec will be equal . . . for both the acquisition conditions (Massaro, 1970c, p 154).

That is, values of d' ought to be bounded at some level greater than zero and evidence equivalent functions over time regardless of interval between S and I tones.

Results of the two experiments are presented in Figure 2. Providing a 500-msec blank interval between the S and I tone did not produce noticable increments in d' compared with the continuous condition within Experiment I. However, an 800-msec silent interval following the 200-msec S tone led to better discrimination in Experiment II. More importantly, the addition of the unfilled retention interval preceding onset of the I tone did not contribute to forgetting.

Within both experiments parallel functions of d' were noted over the retention intervals following both blank and continuous acquisition conditions. In accord with [5], semilog plots of d' showed substantial deviation from linearity as a function of the duration of the I tone. Results over similar intervals reported by Wickelgren (1969) failed to evidence the deviation from linearity. These

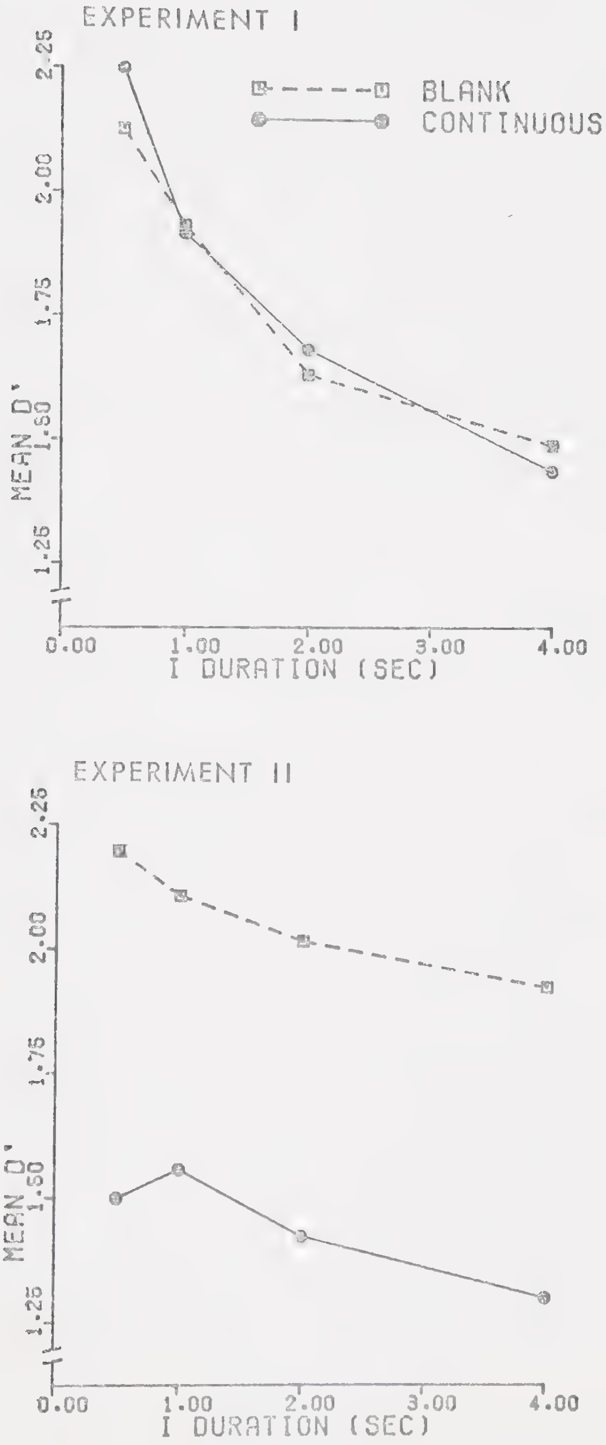

Figure 2. Effects of length of the retention interval and interstimulus interval between S and I tones upon discrimination (from Massaro, 1970c).

results are consistent with Massaro's (1970c) assumption that, while the rate of decay may be exponential, it is not bounded by zero.

Although the results clearly indicated that blank intervals following very brief S tones failed to produce effects associated with forgetting, it is not clear that further consolidation of the S tone was responsible for the phenomenon. In addition, the data do not indicate that, if the trace is further consolidated through the blank retention interval, the rate is equivalent to that while the S tone is present. A crucial test of Massaro's prediction would appear to rest upon comparisons between conditions in which an S tone occupies the entire acquisition period and those in which there is a intertone interval present. If identical levels of discrimination are attained under both conditions, assumptions of equivalent consolidation rates following and during the S tone would appear to be valid. Alternatively, assumptions regarding the consolidation of the S tone trace would require modification.

The possible effects of introducing a blank interval between I and C tones requires some consideration. Propositions of the storage and forgetting model provide for equal consolidation rates for S and I tones. As the S tone is assumed to consolidate through the blank interval between S and I tones, the model must assume that the I tone would consolidate through the intertone interval between I and C tones. Some evidence in support of this assumption was

provided by Massaro (1972). In that study, masking effects of a 40- and 100-msec I tone had equivalent effects on identification of the S tone, even though the shorter I tone occupied only a portion of the retention interval. Providing that these data are indicative of effects producing interference over longer presentation and retention intervals, greater consolidation of the I tone would be predicted as both t_2 and the blank interval between I and C tones increased. That is, including the blank interval would be expected to produce as great an effect upon recognition as when the duration of the I tone equalled the sum of t_2 and the intertone interval between I and C tones.

Similarity of S and I tones. Effects of the I tone upon the S tone trace are explicitly included within the assumptions of Massaro's (1970a, c) model. Consolidation of the I tone acts directly to influence the strength gradient of the S tone. In addition, the similarity of the I and S tone is assumed to influence consolidation (storage) and retention of the S tone directly.

Presentation of an I tone establishes a linear consolidation function similar to that of the S tone but centered about I'. The similarity ("distance") between S and I tones is assumed to influence the effect of the I tone upon the strength gradient of the S tone. When a tone, presumably psychologically dissimilar to the S tone, is employed during the retention interval, decrements in recognition performance are attributed to a relatively pure decay

effect (Massaro, 1970a). However, when the S and I tones are more similar, consolidation of the I tone trace directly influences retention of the S tone. Massaro is rather inexplicit about the nature of this effect, although he suggests that the I tone may serve as a "perceptual anchor" and mediate the recognition process (Massaro, 1970a,p 34, 38).

An alternative way of describing the effect of S and I tone similarity is in terms of an interaction between the S tone trace and the consolidating I tone. The more similar the S and I tones are, the greater the overlap of the two strength gradients. Thus, the S tone trace will continue to consolidate through the I tone period, but only to the extent that the S and I tone distributions overlap. When the difference between S and I tones is small, the S tone trace will continue to consolidate and discrimination should be better than if the S and I tones are dissimilar. Since this effect is the result of the overlap of two normally distributed functions, it should not be a linear function of the similarity between S and I tones. While this hypothesis has not been stated explicitly by Massaro, it is consistent with assumptions of the storage-forgetting model. It is also similar to the "assimilation" hypothesis proposed by Lauenstein (1932) and Pratt (1933).

Two independent experiments attempted to assess the effect of S and I tone similarity (Massaro, 1970a). In the first experiment (Exp I), Ss were presented one of three S

tones (810-, 820-, & 830-Hz) for 1 sec, followed by one of three I tones (S+10, +50, +90 Hz) or "white noise" lasting for 1-, 2-, or 4-sec. The C tones (S or S-10 Hz) immediately followed the I tone interval and lasted for 2-sec. The recognition data were collapsed over S tone frequencies and d' statistics formed for intervals of the I tone. The mean d' statistics are presented in the upper panels of Figure 3.

Recognition was better when the I tone most similar to the S tone frequency filled the retention interval than when either of the other tones were employed. As predicted, the effect upon discrimination was not a linear function of the similarity between S and I tones; virtually no difference existed between conditions of S+50 and S+90 Hz. While the predicted rates of forgetting (decrements in d') were virtually parallel for the three I tone conditions, presentation of "white noise" during the retention interval produced the greatest effects.

The stimuli of Exp II consisted of three S tones (820-, 840-, 860-Hz), three I stimuli (S+20, S+90 Hz, and "white noise") and an unfilled (blank) interval. Duration of the I tone was either 1-, 2-, or 4-sec and immediately preceded a C tone lasting for 2 sec. For one-half of the Ss the C tone was 10 Hz lower than the S tone. In the other group the C tone was 20 Hz lower than the S tone. While the Ss in Exp I were run individually, Exp II was conducted in group sessions and the stimuli were presented over a loudspeaker.

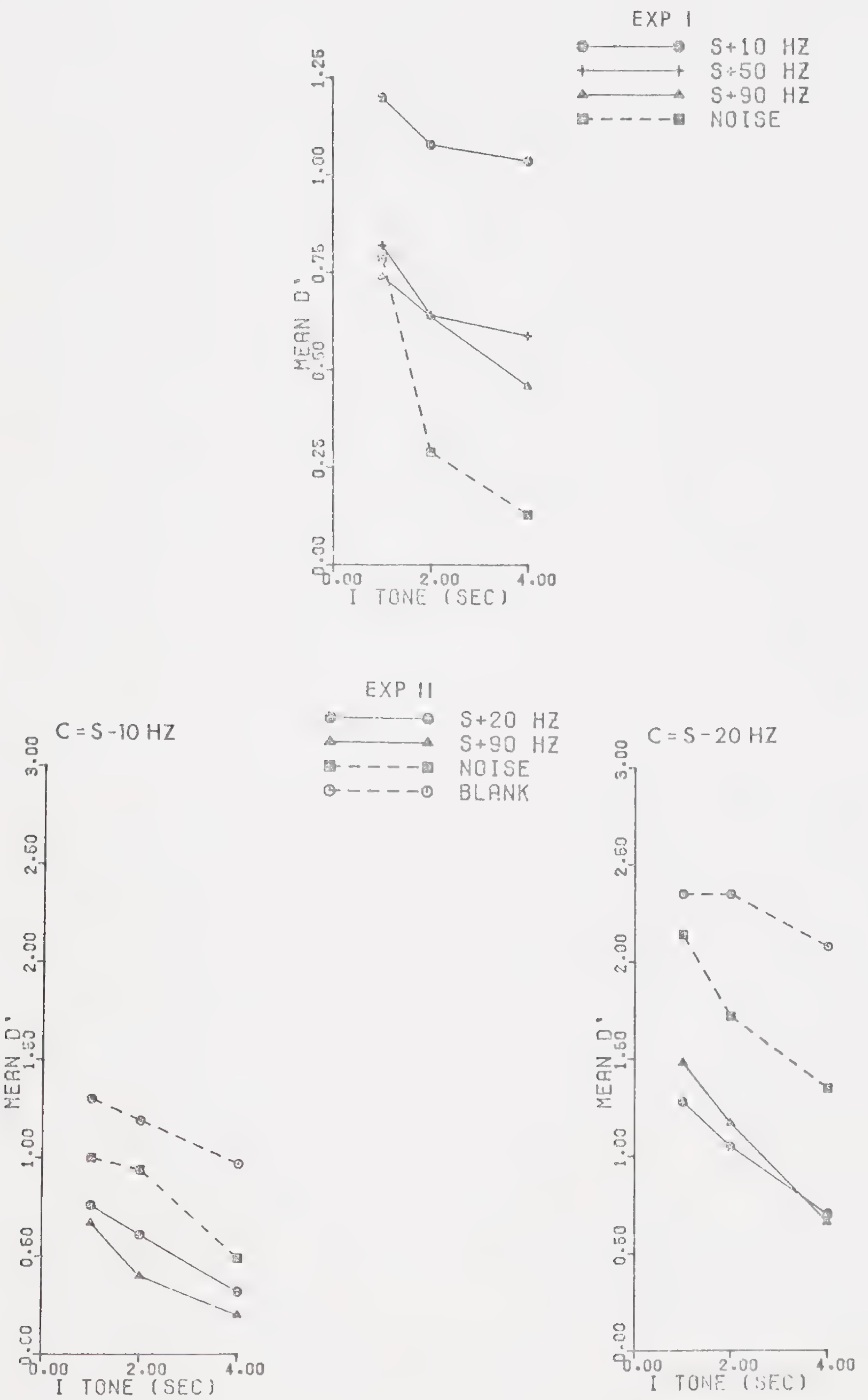

Figure 3. Discriminability (d') as a function of the similarity between S and I tones and length of the retention interval (From Massaro, 1970c).

The recognition data were collapsed over S tone frequency and d' statistics formed for the _S_s. Results are presented in the lower panels of Figure 3.

Discrimination was far less consistent with the theoretical predictions than the results of Exp I. As expected, discrimination was reduced when the retention interval was filled with a specific I tone frequency as compared to the blank retention period. There was virtually no difference, however, between the S+20 and S+90 Hz conditions. In both C tone conditions "white noise" during the retention period failed to evidence the substantial forgetting rates present in Exp I. While some forgetting was evidenced under the blank retention interval for C = S-10 Hz, little or no forgetting occurred when C = S-20 Hz.

A number of possible explanations for these results can be provided. Massaro has suggested that the I tone may "give _S_s a perceptual anchor" (1970a, p 34) or may be a "reference point that could be employed to judge the difference between S and C tones" (9170a, p 38). However, these suggestions are not incorporated explicitly within assumptions of consolidation and storage (Massaro, 1970a, c), and the "strength criterion" process of discrimination (Massaro, 1970a, b, c). It is quite possible that the response strategies adopted by the _S_s in Exp I were quite different than those employed when the stimuli were presented over the loudspeaker (p 37, 39). It is most conceivable, however, that the discrepancies resulted from

poor control procedures within Exp II.

Interaction of storage and forgetting. The data of Exp I (Massaro, 1970a) clearly support both Massaro's "perceptual anchor" explanation and an interpretation in terms of an "assimilation hypothesis" discussed earlier. The similarity between the S and I tone frequencies significantly influenced recognition performance. The effect was a nonlinear function of the similarity between S and I tones (Exp I). Although recognition performance was reduced compared to a blank interval (Exp II), the degree of similarity between S and I tones served to facilitate discrimination following a "filled" retention interval (Exp I, II).

Massaro has aruged the presentation of the I tone not only terminates consolidation of the S tone but "decreases [sic] the memory strength of the S tone directly proportional to the amount of consolidation of the interference tone" (Massaro, 1970c, p 154) and the similarity between the S and I tones (Massaro, 1970a, p 39). His data, as well as his assumptions regarding consolidation [4], suggest that presentation of the I tone does not invariably decrease the strength of the S tone trace. In fact, as the similarity between S and I tones increases, discrimination improves. This is most reasonably accounted for by assuming that the I tone results in further consolidation or at least maintenance of the asymptotic strength of the S tone trace. Simply, if the difference between the S and I tones is

small, a greater portion of the consolidating I tone trace overlaps the S tone gradient, hence eliminating decay.

Two effects of the similarity between the S and I tones may be derived from the addition of an "assimilation" hypothesis to the storage-forgetting model. First, the distribution of the S tone trace is altered by consolidation of the I tone, becoming skewed in the direction opposite the I tone frequency. Those portions of the S tone trace in proximity of the I tone retain their strength or are consolidated further. Those portions farther from the I tone frequency are less subject to the effects of the consolidating trace and are reduced in strength by decay. A second effect resulting from this process is a shift in the 'mean' of the S tone gradient. When the S and I tone gradients overlap, the joint effect of the decay of the S tone gradient and consolidation of the I tone shifts S' in the direction of I'. Put another way, the S tone trace is assimilated by the consolidating I tone. The amount of assimilation is a curvilinear function of the similarity or overlap between S and I tone distributions.

The latter effect is consistent with the evidence of changes in d' as a function of S and I tone similarity. If d' is taken to be the difference between the means of the S and C tone gradients (Wickelgren, 1966, 1969; Massaro, 1970a, c), previous results coincide with predictions of a shift in S' as a function of its proximity to the I tone. Consider Wickelgren's (1969) experiment (cf., Figure 1).

Under conditions in which the I and C tones were in opposite directions from the S tone (i.e., I > S and C < S, or I < S and C > S), discriminability (d') between the S and C tones was improved as the difference between the S and I tones was increased from 15- to 40-Hz. Massaro (1970a, Exp I) also showed that discrimination was superior when the I tone was similar to the S tone frequency. These data make it clear that Wickelgren's (1966, 1969) simple decay hypothesis of pitch discrimination is incorrect. However, the nature of the effect of S and I tone similarity upon pitch memory remains unclear. While Massaro (1970a, c) has suggested that Ss may employ the I tone as a "perceptual anchor" to mediate the discrimination process, an hypothesis suggesting an "assimilation" of the S tone trace by the I tone is more consistent with assumptions of the storage-forgetting model, and also accounts for the available data.

No one study has effectively sampled the conditions of S and I tone similarity to test adequately these assumptions. In addition, no study has considered the predicitions for what appears to be a counter-intuitive case.

On any trial, the selection of S, I and C tone frequencies results in one of three arrangements of the tones. Figure 4 presents a schematic representation of these conditions. The first condition, identified as a Contralateral arrangement of I and C tones, occurs when the frequencies of the I and C tones are in opposite directions

from the S tone. Two possible arrangements result from placing the I and C tones in the same direction from the S tone. For the case identified as Ipsilateral: 1, the I tone frequency is within the interval between the S and C tones. In the arrangement identified Ipsilateral: 2 the I tone is placed outside the interval between S and C tone frequencies.

Consider the predicted effect of locating the I and C tones ipsilateral to the S tone. Under these conditions, as S' is shifted toward I' by the consolidation of the I tone, the effective distance between S and C tones is reduced. Wickelgren's (1969) data showed just this effect; cf., Figure 1. The distance between S and C tone gradients, as evidenced by d', was reduced as the result of increasing the S and I tone difference. If the S and I tone difference was more than 40 Hz, ipsilateral and contralateral placement of I and C tones resulted in equivalent discrimination. Massaro has never reported data for conditions similar to those of Wickelgren's study.

A counter-intuitive prediction arises when the I tone is located in the interval between S and C tone frequencies. An assimilation hypothesis appears to predict a shift in S' which is independent of the C tone frequency. Hence, placing the I tone between the S and C tones should reduce the distance between S' and C' and, accordingly, reduce discrimination. Yet the placement of tones in such a manner represents a "tonal staircase" (i.e., S > I > C or S < I <

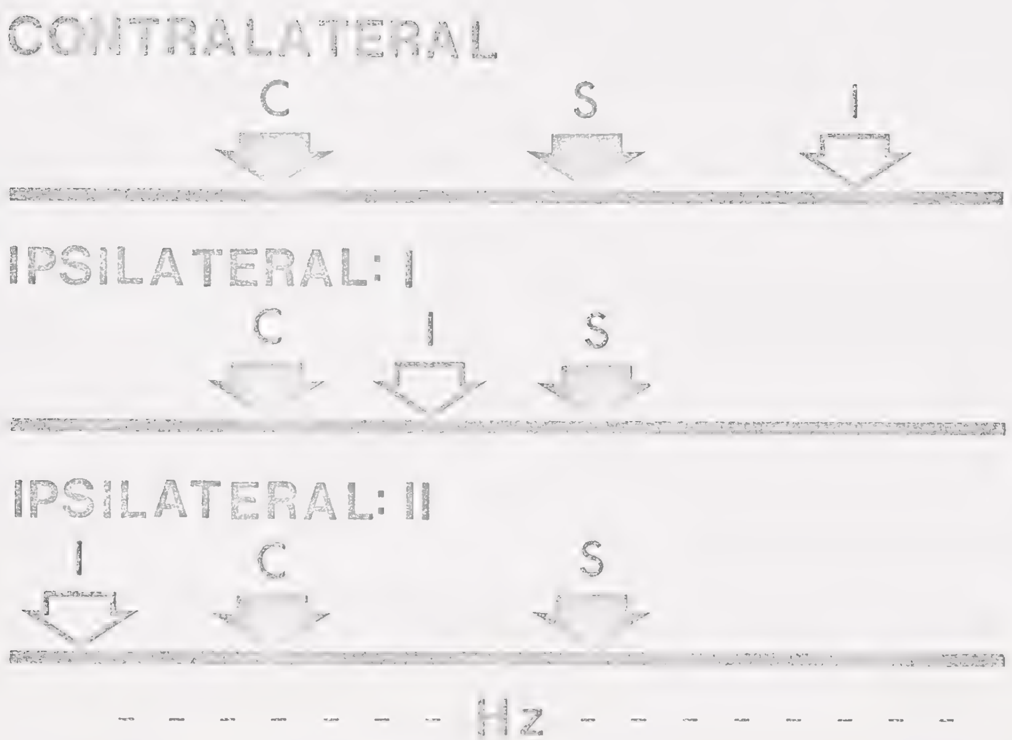

Figure 4. Schematic representation of experimental conditions for contralateral and ipsilateral placement of I and C tones. Contralateral conditions are characterized by the placement of I and C tones in opposite directions from the S tone. Conditions in which the I and C tones are in the same direction from the S tone are identified as Ipsilateral placements. In Ipsilateral: 1, the I tone occupies the interval between S and C tones, resulting in the perception of a "tonal staircase." In Ipsilateral: II, while the I and C tones are in the same direction from the S tone, the I tone is placed outside the interval between the S and C tones.

C) and, intuitively, should afford the greatest discriminability. Such results would be inconsistent with an assimilation hypothesis. In addition, these results would suggest that either the assumptions regarding storage and forgetting, or the discrimination process are inadequate.

The following experiment was designed to provide a sufficent test of the storage-forgetting model of pitch memory. The predictive validity of an "assimilation" hypothesis interpretation of the effects of S and I tone similarity was also assessed. Both contralateral and ipsilateral placements of the I and C tones about the S tone were employed. A critical set of conditions was provided by occasions in which the I tone was placed between the S and C tone frequencies.

EXPERIMENT 1

Method

Subjects

Twenty male and female students from introductory psychology classes participated in the experiment to fulfill course requirements. The data of one *S* was discarded when his results indicated gross errors in the original responses.

Design and Procedure

Two standard (S) tones (810- and 880-Hz), four interference (I) tone frequencies (S-10, -30, -50 and -90 Hz) and five comparison frequencies (S±20, ±40 and S Hz) constituted the stimuli of the present experiment. In addition, an unfilled (blank) retention interval was incorporated as frequently as any of the I tone frequencies. Three random permutations were formed of the 50 factorial combinations of S, I and C tone conditions. Each *S* participated in five replications of the experiment, receiving all orders of presentation at least once.

The stimuli were produced by three Heathkit (model 1G-18) sine-wave audio generators, calibrated to within 1% accuracy of one another. The selected frequencies for the trials were recorded on magnetic tape, through a 3-channel multiplexing switch, at an amplification 10 times the source voltage (20 db, .01v ref.). Onset of the tones was gated through solid state integrating switches on each of the

channels. Durations of the stimuli (all 1 sec) were controlled by an additional square wave generator and digital logic of the multiplexing switch.[4] Intertrial intervals were maintained roughly at 6-sec by means of a stopwatch. No attempt was made to control for apparent loudness of the tones, although there was little apparent difference among them.

The stimuli were presented to each S through stereo headphones, at what was judged by the S to be a "comfortable level," as he sat within an acoustically dampened chamber. After the S was seated at a desk within the chamber, a set of instructions were provided which fully described the nature of the experiment. Essentially, the Ss were told that during the experiment they would hear a series of brief tones followed by a 6-sec blank interval. During this interval they were to judge whether the first and last tones of the series were the "same" or "different," and to indicate their decision by checking one of two labeled positions on a numbered answer sheet. Following four practice trials, the first three blocks (replications) were presented. A 5-min rest period was then provided while the tape recording was positioned for the next series. The final two blocks were presented immediately following the

---

[4]Mr. Pat Wong and Mr. Paul DeGroot assisted in the design and testing of this apparatus. The experiment utilized the facilities of Dr. Stanley Rule's laboratory. Their guidance and assistance in the preparation of this experiment is greatly appreciated.

rest period and were not preceded by practice trials. The entire session required approximately 55 min.

Results

Discrimination judgments ("same", "different") were pooled across replications and S tone frequencies for each S and proportions correct and incorrect recognitions were formed for each of the experimental conditions. The index of detectibility (d') was calculated for each of the C ≠ S tone comparison conditions by means of tables provided by Hochaus (1972). The proportion of correct recognitions for C = S tones ("same") formed the "hit-rate" for each I tone condition and incorrect recognitions for C ≠ S tones estimated "false-alarms". The mean d' statistics for the 20 C ≠ S experimental conditions are presented in Figure 5.

An analysis of variance (Table 1) confirmed the obvious effects within the data.[5] A difference of 40-Hz between the S and C tones was better detected than was a 20-Hz difference, $F(3,54) = 71.95$. Increasing the difference (reducing the similarity) between the S and I tones led to a general reduction in discrimination as evidenced by the significant main effect of I tone frequency, $F(4,72) = 8.48$, $p < .01$. It was clear, however, that the effect of the I tone was dependent upon the frequency and locus of the C

---

[5]An identical analysis conducted upon the mean proportion of correct discriminations yielded equivalent results but is not reported here. Previous studies have employed d' as the measure of discriminability, and in order to maintain comparability that statistic was selected in this study.

Figure 5. Effects of the similarity between S and I tones and placement of the I and C tones upon discriminability (d'): Experiment 1.

Table 1

Summary of Analysis of Variance:

Mean d' Statisitics.

SOURCE	SSQ	df	MSQ	F
SUBJECTS [O]	309.999	18	17.222	
WITHIN SUBJECTS	234.655	19	12.350	
I TONE [I]	65.803	4	16.451	8.48 **
C TONE [C]	131.888	3	43.963	71.95 **
I x C	36.964	12	3.080	8.53 **
RESIDUAL	250.635	342	.733	
O x I	139.677	72	1.940	
O x C	33.004	54	.611	
O x I x C	77.954	216	.361	
TOTAL	792.289	379	2.098	

* *p* < .05
** *p* < .01

tone; $F(12,216) = 8.53$ $p < .01$, for the C x I interaction.

Introducing a contralateral I tone equal to S-10 Hz led to significant reduction in discrimination relative to the blank retention interval for both S+20 and S+40 Hz C tone conditions, $F(1,216) = 37.33$ and 8.70, $p < .005$, respectively. However, if the I and C tones were ipsilateral to the S tone, discrimination was not reduced significantly by the same I tone frequency, $F(1,216) = 3.29$ and 2.10, $p > .05$ for C = S-40 and S-20 Hz, respectively. That is, if the I tone was placed within the interval

between the S and C tone frequencies (cf, Ipsilateral: I, Figure 4) discrimination was a good as that following the blank retention interval.

An I tone placed beyond the S and C tone interval (cf, Ipsilateral II, Figure 4) led to a significant reduction in discrimination for both S-40 and S-20 H C tones. For instance if the I tone was S-30 Hz, discrimination of the 20 Hz difference between S and C tones was significantly different than that for the blank retention interval, $F(1,216) = 7.75$, $p < .01$. Discrimination in this case remained superior to the contralateral conditions, however. A similar reduction in discrimination was evidenced when the I tone was S-50 Hz and the C tone was S-40 Hz, $F(1,216) = 6.22$, $p < .01$.

Discussion

Introduction of an I tone during the retention interval substantially reduced pitch discrimination. As expected, the effect was dependent upon both the similarity between the S and I tones and the similarity between S and C tones. In addition, discrimination was dependent upon the locus of the I and C tones relative to the S tone, but the effects were not consistent with expectations of an assimilation hypothesis, nor predicitions of the storage-forgetting model (Massaro, 1970a, c).

In conditions relicating Massaro's (1970a) procedure (i.e., when the I and C tones were contralateral to the S tone), an I tone of S-10 Hz produced substantial interfer-

ence compared with performance following the blank retention interval. Increasing the difference between S and I tones led to some improvement in discrimination, but performance never reached a level equal to that of the blank retention interval. These results generally support predictions of an assimilation hypothesis, but they are not consistent with Massaro's (1970a) data.

When the I tone was similar to the S tone, superior performance was attained if the I tone and C tones were ipsilateral to the S tone, rather than on opposite sides of the S tone (contralateral). This superiority in performance was lost, however, as the I tone became less similar to the S tone. These results are consistent with the data from Wickelgren's (1969) study of S and I tone similarity, but he argued that the effect was not due to interference produced by the I tone.

An interesting effect, not available in Wickelgren's study, was also evidenced in the present data. If the frequency of the I tone is between those of the S and C tones, presentation of the three tones is perceived as a "tonal staircase." Discrimination under these conditions was not substantially different than that following the blank retention interval. Interference was not demonstrated until the I tone frequency was located beyond the S and C tone interval. Such results are not consistent with an assimilation hypothesis, and assumptions of a shift in the S tone memory trace as a function of the similarity between S

and I tones. Stated simply, that hypothesis would predict that interference should be evidenced by ipsilateral I and C tones, with decreasing levels of discrimination as the difference between the S and I tone increased. Neither the present data, nor his own, can be accommodated by Wickelgren's associative strength theory, since familiarity is *assumed* to be unaffected by locus of the I tone.

Massaro (1970a) has suggested that *S*s may employ the I tone as an "anchor point" in judgments of the difference between S and C tones. More particularly, Wickelgren (1969) proposed that discrimination in certain circumstances may result from successive pitch-difference judgments. That process might resemble the following: When the I tone is presented, a judgment is formed of the direction and relative magnitude of its difference from the S tone. A similar judgment of the I and C tone difference accompanies presentation of the C tone. Discrimination would then be based upon the transitivity of the two successive judgments.

Consider the case of ipsilateral placement of I and C tones. When the I tone occupies the interval between S and C tones, the relationship among the three tones is $S > I$ and $I > C$ and, hence, $S > C$. When the I tone is located beyond the C tone frequency, but is similar to the C tone, successive judgments of the form $S >> I$, $I < C$ and, then, $S < C$ would lead to the lack of interference noted in the present study. Discrimination would then be a joint function of the similarity between S and C tones as well as

between I and C tones. The process would encounter difficulties, and discrimination would be reduced, in situations such as S >> I and I << C, as when the C tone is S-20 Hz and the I tone is S-50 Hz.

While these suggestion may account for the results under conditions of the ipsilateral placement of I and C tones, they are untenable when the I and C tones are contralateral to the S tone. First, any increase in the S - I tone difference in these conditions produces a corresponding increase in the I - C tone difference. If a successive discrimination process was adopted by the *S*s, detection of the S - C tone difference should be influenced, however, by the *relative* inequality between the S - I and I - C tone differences. The relative inequalities decrease as the difference between the S and I tones increases. When C = S+20 Hz, for example, and I = S-10 Hz, S > I and I >> C, but if the I tone is S-30 Hz, S >> I and I >> C. Hence, discrimination should be more difficult as the difference between the S and I tones increases. There was some evidence of this effect for C = S+20 Hz when the I tone was located at S-10 vs S-30 Hz. But when the I tone was S-50 Hz, and the relative inequality of the S - I and I - C differences was reduced, discrimination improved.

Secondly, a successive discrimination process would assume symmetry of the effects about the S tone, but as a function of the transitivity of the inequalities. Consider, for example, the case in which C = S-20 Hz and I = S-30 Hz

(S >> I and I < C), compared with the case in which C = S+20 Hz and I = S-10 Hz (S > I and I << C). Equal levels of discrimination would be expected under these two conditions if recognition resulted from the process of successive discrimination. It was evident, however, that the latter condition substantailly reduced dscrimination.

One of the procedural limits of the present experiment was the consistent placement of the I tone so that it was always lower than the S tone. It is not clear what effects this might have had upon performance, but it is conceivable that it provided a set for the *S*s which biased their responses. One suggested indicant of response bias within detection and recognition tasks has been the proportion of "false alarms" (Aiken & Lau, 1968; Moss, et al., 1970; Massaro, 1970a). An analysis of variance was conducted upon the proportion of "same" responses (Table 2) under the four S $\neq$ C conditions of the present experiment. A summary of that analysis is presented in Table 3.

The tendency to respond "same" increased as the similarity between S and I tones decreased, $F(4,72) = 3.68$, $p < .01$, and the similarity between S and C tones increased, $F(3,54) = 55.58$. While, overall, *S*s responded "same" at equivalent rates if the C tone was lower (.203) or higher (.231) than the S tone, the I x C interaction was significant, $F(12,216) = 11.89$. The source of this interaction was due to the fact that, with ipsilateral placement of the I and C tones, *S*s were less 'biased' to

Table 2

Proportion of "Same" Responses as a Function of Difference Between S and C Tones and Frequency of I Tone

	C TONE (Hz)				
I TONE	S-40	S-20	S+20	S+40	MEAN
"Blank"	.100	.232	.284	.116	.183
S-10	.032	.153	.363	.064	.153
S-30	.032	.189	.516	.089	.207
S-50	.063	.526	.358	.100	.262
S-90	.158	.542	.321	.100	.280
MEAN	.077	.328	.363	.094	

respond "same" when the I tone was similar to the C tone than when it was more distinct.

Bias, in this sense, must be assumed to include not only general factors which may influence the S's tendency to respond in a particular fashion, but also specific effects of experimental conditions which affect the S's decision system (Green & Swets, 1966). Such data have been viewed in terms of the influence of experimental conditions upon the S's decision criteria (Bindra, et al., 1965; Aiken & Lau, 1966; Moss, et al., 1970) or his response strategy (Massaro, 1970a; Siegel, 1974).

Table 3

Summary of Analysis of Variance:

Proportion of "Same" Responses When

S and C Tones Differed.

SOURCE	SSQ	df	MSQ	F
SUBJECTS [O]	4.568	18	.254	
WITHIN SUBJECTS	10.250	19	.540	
I TONE [I]	.869	4	.217	3.68 **
C TONE [C]	6.668	3	2.223	55.58 **
I x C	2.713	12	.226	11.89 **
RESIDUAL	10.494	342	.031	
O x I	4.236	72	.059	
O x C	2.172	54	.040	
O x I x C	4.087	216	.019	
TOTAL	25.312	379	.067	

* $p < .05$
** $p < .01$

The present data may indicate the influence of the I tone upon the criteria of judging the S and C tones "same" or "different." Massaro (1970a) has also suggested that the similarity between the S and I tones directly affects the S's decision criterion.

> With dissimilar I stimuli, the S and C tones were perceived as very similar to each other relative to their similarity to the distinctive I stimulus. Therefore, Ss in the present experiment required a much larger difference before they said "different" with a dissimilar I stimulus than with a similar I stimulus. (p 38)

Both he and Wickelgren (1969), however, have suggested that the effects also may be due to differences in response strategy as a function of the arrangment of the tones.

When the I and C tones are ipsilateral to the S tone and similar to one another, the _S_ may employ the relational properties among the stimuli to form his judgment of "sameness." That is, he may use the successive discrimination process described above. When the I and C tones are distinct (either with extreme I tone frequencies under ipsilateral arrangements or when the I and C tones are contralateral to the S tone), an alternative strategy is adopted. The nature of the alternative strategy is not clear. The _S_s could be employing pitch-difference and, as the storage-forgetting model suggests (Massaro, 1970a, b), pitch-difference is influenced by the similarity between S and I tones. Decisions may be made on the basis of familarity (Wickelgren, 1969) and effects of the I tone upon recognition may be the result of shifts in the decision criteria (Bindra, et al., 1965; Aiken & Lau, 1966; Jesteadt & Sims, 1975).

Pitch discrimination following a filled retention interval was influenced by the similarity between the S and I tones. Clearly, there was an asymmetry of the effect of S and I tone similarity in the data. The effect was dependent upon the locus of the I and C tones, but the factors responsible for its occurrence were not obvious. In the following experiment, an attempt is made to isolate the

factors responsible for interference within the pitch discrimination task.

EXPERIMENT 2

The results of Experiment 1 indicated that effects of an I tone are dependent upon both the similarity between the S and I tones and the I and C tones. While the evidence was not consistent with an assimilation hypothesis, Massaro's (1970a, c) storage-forgetting model, nor assumptions of the associative strength model (Wickelgren, 1969), the origin of the effects was not clear.

Experiment 1 had certain advantages over previous designs by providing for contralateral and ipsilateral placement of the I and C tones about the S tone. The I tone frequency, however, was always lower than that of the S tone. It was suggested that this ordering may have led _S_s to adopt one strategy when the C and I tone were ipsilateral to the S tone, and another strategy under contralateral placement of the tones. The following experiment provided ispsilateral and contralateral placement of the I and C tones, and the tones were both higher and lower than the S tone.

In previous studies, the d' statistic has been interpreted as representing the difference between the means of the strength gradients for the S and C tones (Massaro, 1970a, c; Wickelgren, 1966, 1969). Presumably, decrements in d' reflect reductions in the difference between S' and C'. Moreover, Massaro (1970a, c) has assumed that presentation of the I tone directly influences the S tone memory

trace. While Massaro has suggested that the effects come about because the I tone serves as a perceptual anchor, the effect of the similarity between S and I tones may also be be explained as resulting from a shift in the mean of the S tone gradient Specifically, the similarity between S and I tones affects the degree to which the S tone trace is assimilated by the intervening tone (Pratt, 1933; Deutsch, 1972b). This prediction has not been tested directly.

While d' may measure the distance between S' and C' when the stimuli do not have the same frequency, it does not provide a measure under conditions where S and C tones are equivalent. Yet, this condition provides a crucial test of an assimilation hypothesis, by providing the opportunity to clearly demonstrate effects of the I tone upon the S tone memory trace. An apparent solution to the limits of TSD appears to rest within a procedure requiring the S to form estimates of the difference between S and C tones, rather than simply judging whether they are "same" or "different."

Such judgments provide estimates of the magnitude of the difference between the tones which may be assessed directly. In addition, the procedure appears to provide for a direct test of the assimilation prediction by assessing the perceived difference between equivalent S and C tones as a function of the I tone frequency.

Method

Design and Procedure

Each *S* was taken to an acoustically dampened experimental chamber and provided instructions which fully described the purpose of the experiment. The first two sessions were devoted to a training procedure and practice sessions. The remaining sessions constituted the experimental procedure.

Practice Sessions. The tonal stimuli of the practice sessions consisted of combinations of S and C tone frequencies which included those that would occur during the experimental sessions. Eight S tone frequencies, ranging between 700- and 960-Hz in 40-Hz increments, and 11 C tone frequencies (S±60, ±40, ±30, ±20, ±10, and S Hz) were factorially combined to form the 88 trials of any session. Five random sequences of the trials were formed, of which each *S* recieved two distinct orders. The stimuli were generated by means of the D-A logic of a PDP-12 computer and a Wavetech (model 116) voltage controlled, audio oscillator.

The *S* initiated each trial of the experiment by pressing a push-button mounted on a panel in front of him. Two seconds following the lighting of a signal lamp, the S tone was presented for 1.5-sec, followed by a 500-msec slient retention period, and then the C tone presented for 1.5-sec. The sequence and durations of the stimuli were

controlled by a computer program.[6] Following presentation of the stimuli, the S was instructed to judge the difference between the pitch of the two tones.

Judgments of the magnitude of the difference between the pitch of the tones were made by means of graphic ratings. The S was provided a booklet of 8.5- x 11-in paper, each sheet containing 12 lines 12 cm long. The ends of the lines were labeled "much lower" and "much higher", with the centre labeled "same". The S was instructed to estimate the magnitude of difference between the S and C tones and to record the difference by placing an "X" at some point along the line. If the C tone appeared to be lower than the S tone, the S was instructed to place the "X" along the line in the direction of the "much lower" end. Conversely, if the C tone was higher than the S tone, the "X" was to be placed along the other half of the line. The magnitude of the difference between S and C tones was indicated by the proximity of the "X" to the end of the line. That is, the closer the "X" was to the end of the line the larger the perceived difference. Each training session lasted approximately one hour and was halted midway to provide the S with a 10-min rest period.

Experimental Sessions. Following the two training

---

[6]This experiment utilized the facilities of the Psychron Laboratory within the Department of Psychology. The cooperation and assistance of Dr T. Nilsson in the design and construction of the apparatus is appreciated greatly.

sessions, the Ss were given instructions individually for the second phase of the experiment. Essentially, the S was told that all conditions of the first sessions were included in the second, with the exception that an intervening tone would likely occur between the S and C tones. The S was implicitly told to ignore the I tone, should it occur, and to attend to the difference between the first and last tone of the series. All other instructions remained identical to those of the training session.

Each S served in three independently ordered replications of the experimental conditions. The 308 trials of each replication were formed by factorially combining four S tone frequencies (780-, 810-, 840-, and 870-Hz), seven C tones (S±30, ±20,±10, and S Hz), and 10 I tone frequencies (S±5, ±15, ±25, ±40, and ±100 Hz). In addition, an unfilled retention interval occurred as often as any I tone frequency. The duration of the S and C tones was 1.5 sec, separated by a 1-sec retention period. All other conditions of the experimental sessions were identical to those of the training sessions.

Data were collected in successive 1 hr sessions (no more than one per day), with a 10-min rest period provided midway through each session. Each replication required approximately 1.75 hr to complete.

Subjects

The Ss were four volunteers who were paid $20 for their participation. The training and experimental sessions

required no less than 8 hrs to complete. Two of the Ss (TJ and CC) had previously served in experiments requiring psychophysical judgments.

Results

The data of each experimental session consisted of four replications of difference judgments for each of the S, I, and C tone combinations, one at each S tone frequency. Initially, the data were scored in terms of deviations from "equality," as estimated by the mean judgment associated with a 0-Hz difference between S and C tones following a blank retention interval. To increase the number of observations at each S, I, and C tone combination for each S , the difference judgments were then combined for equivalent tone-difference relationships. For example, the estimates of the difference for a C = S+20 Hz in the presence of an I tone 15 Hz lower than the S tone were combined with the difference judgments for C = S-20 Hz and I = S+15 Hz. The mean pitch-difference judgments, formed over the 24 combined observations for each S, are presented in Figure 6 for the S and C tone difference conditions.

Values along the abscissa of Figure 6 represent the magnitude of the difference between S and I tones, and the position of the I tone with respect to the S and C tones. When S ≠ C the data points at +40 Hz, for example, are means formed over conditions in which the I tone was 40-Hz different than the S tone and ipsilateral to the C tone, while data points at -40 Hz are means formed over the same S

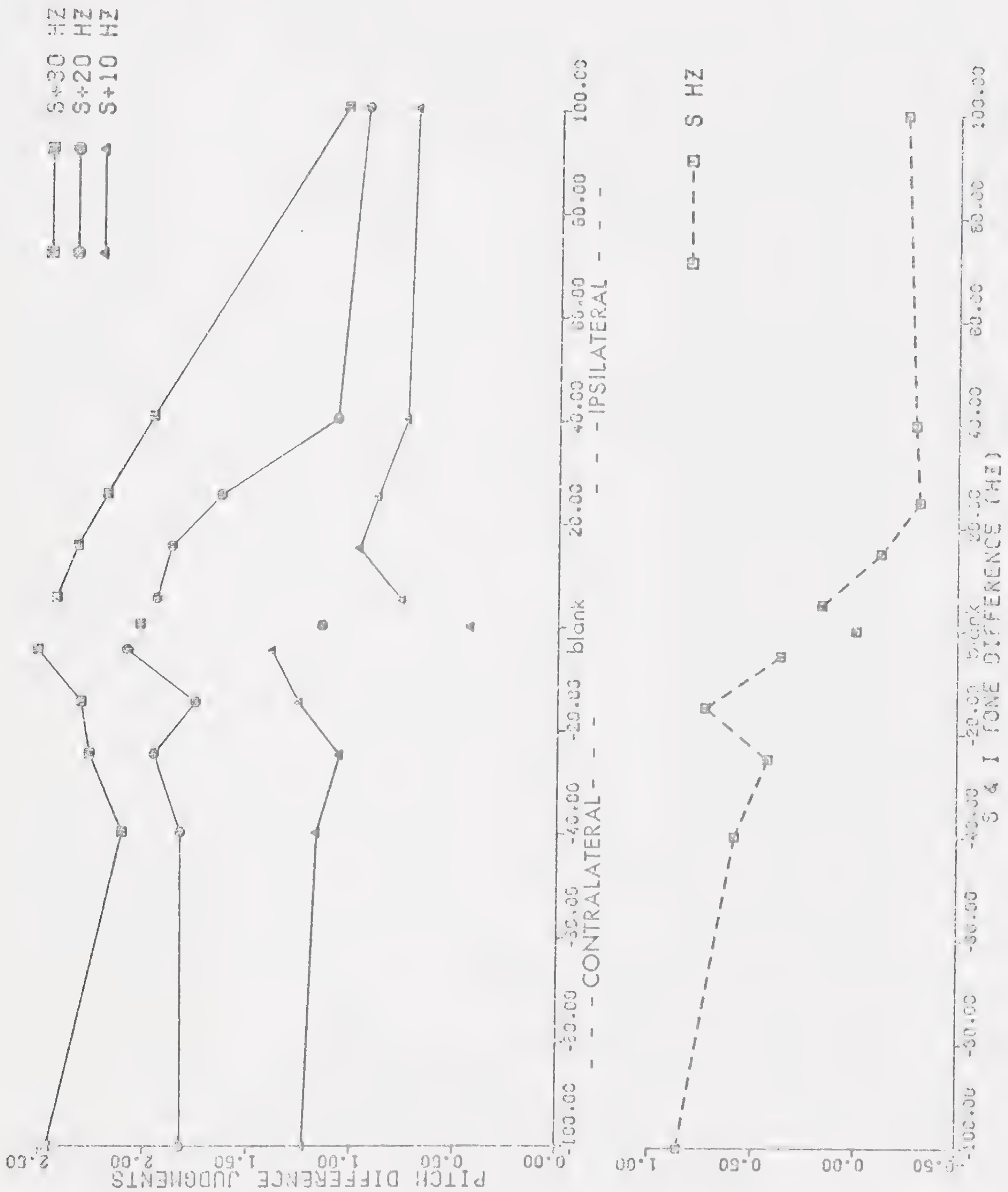

Figure 6. Mean pitch difference judgments as a function of the similarity between S and I tones and placement of the I and C times: Experiment 2.

and I difference but under conditions of contralateral I and C tones. For conditions in which the S and C tone were identical (i.e.,C = S Hz), values along the abscissa are the I - S tone difference.

A rather surprising outcome of the experiment was the fact that, in nearly every case, judgments of the difference between S and C tones were enhanced by the occurrence of an I stimulus during the retention interval. The most notable exception to this occurred when S and C tones were identical. Judgments in these conditions were the most indicative of "assimilation" of the S tone by differing I tones. The C tone was judged "higher" than the S tone if the I tone was lower in frequency than the S tone. Correspondingly, when the I tone was higher than the S tone, the C tone was judged "lower" that the S tone.

Effects of the similarity between S and I tones were apparent under conditions in which the S and C tones differed, as well. The functions of pitch-difference judgments differed for ipsilateral and contralateral I and C tones. It was rare, however, that the degree of "interference" produced by ipsilateral I and C tones, or the "facilitation" function under contralateral conditions matched that of the S = C tone conditions.

An analysis of variance was conducted on the mean pitch-difference judgments, excluding those following the blank retention interval. In addition, a dummy variable (LOCUS I & C) was introduced to divide levels of S and I

tone similarity into ipsilateral and contralateral I and C tone conditions. A summary of that analysis is presented in

Table 4

Summary of Analysis of Variance:

Mean Pitch-Difference for Conditions

Involving an I Stimulus.

SOURCE	SSQ	df	MSQ	F
SUBJECTS [O]	23.940	3	7.980	
WITHIN SUBJECTS	106.605	39	2.734	
I TONE [I]	2.930	4	.733	4.44 *
C TONE [C]	85.784	3	28.595	14.80 **
I x C	2.363	12	.197	1.79
LOCUS I & C [L]	9.032	1	9.032	4.03
L x I	2.990	4	.748	3.38 *
L x C	1.058	3	.353	3.53
L x I x C	2.448	12	.204	1.57
RESIDUAL	38.298	117	.327	
O x I	1.981	12	.165	
O x C	17.392	9	1.933	
O x I x C	3.953	36	.110	
O x L	6.730	3	2.243	
O x L x I	2.654	12	.221	
O x L x C	.899	9	.100	
O x L x I x C	4.689	36	.130	
TOTAL	168.844	159	1.062	

* $p < .05$
** $p < .01$

Table 4.

A significant effect of the difference between S and C tones upon the pitch-difference judgments was evidenced,

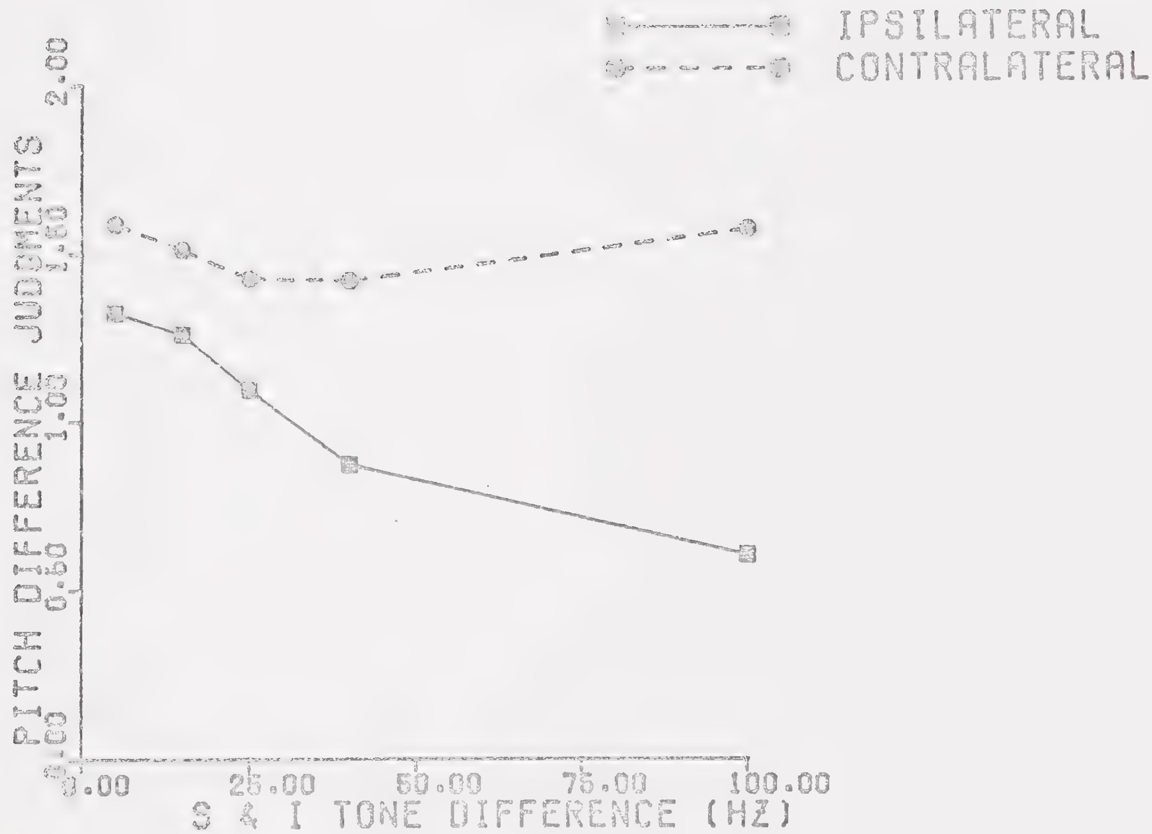

Figure 7. Effects of the interaction between S and I tone similarity and placement of the I and C tones upon mean pitch difference judgments: Experiment 2.

$F(3,9) = 14.80$, $p < .01$. Similarity between the S and I tones affected the magnitude of the judgments, $F(4,12) = 4.44$, $p < .05$, but this interacted with the locus of the I and C tones, $F(4,12) = 3.38$, $p < .05$. Means for the L x I interaction (Figure 7) clearly show the nature of the effect. When the I and C tones were ipsilateral to the S tone, increasing the difference between S and I tones decreased the magnitude of the pitch-difference judgments. For contralateral I and C tones, however, the judged difference between S and C tones showed little effect resulting from the similarity between S and I tones. An analysis of trends of the L x I interaction demonstrated significantly different linear trends between contralateral and ipsilateral I and C tone conditions, $F(1,12) = 13.18$, $p < .01$. Judgments of pitch difference under conditions of ipsilateral I and C tones decreased as the S and I tone difference increased. For contralateral I and C tones, the judgments remained relatively unaffected by the difference between S and I tones. This difference in linear trend accounted for 97.5% of the variation attributed to the L x I interaction. None of the remaining interactions or main effects of the analysis of variance were significant.

Discussion

An assimilation hypothesis, as it applies to the storage-forgetting model (Massaro, 1970a, c), predicts three distinctive characteristics within judgments of pitch-difference; if such judgments are to be consistent with

previous interpretations of d' (Green & Swets, 1966; Wickelgren, 1966, 1969; Massaro, 1970a, c).

First, the judged differences between S and C tones should be curvilinear functions of the similarity between the S and I tones. Under conditions in which the I and C tones are presented on opposite sides of the S tone (contralateral to the S tone), judged differences should increase initially as the difference between S and I tones is increased and return to a level equivalent to the blank retention interval as the difference between S and I tones becomes extreme. When the I and C tones are ipsilateral to the S tone, an opposite effect should be noted. Initially, judgments should be less than those following the blank retention interval, should decrease more as the difference between S and I tones increases, and return to the level of the blank retention interval at extreme S and I tone differences.

Only conditions in which the S and C tones were identical evidenced effects which approximated this prediction. With the exception of two cases under the C = S+20 Hz condition and one for C = S+30 Hz, the presence of any I tone during the retention interval substantially increased the magnitude of the judgments between physically different stimuli. The functions of pitch-difference judgments were statistically different for ipsilateral and contralateral I and C tones. The differences, however, were due principally to differential slopes of linear trends

associated with the difference between S and I tones. For contralateral I and C tones, judgments of pitch difference did not show the curvilinearity predicted by an assimilation hypothesis. In fact, there was a tendency for the trend to be in the direction opposite to the prediction when $C \neq S$. If the I and C tones were ipsilateral to the S tone, judgments typically showed a steady decrease in magnitude as the difference between S and I tones increased.

Secondly, the range and magnitude of the I tone effect should be equivalent for I and C tones which are ipsilateral or contralateral to the S tone. Thus, following the first prediction, the curves should be mirror-images of one another. The interaction between locus of the I and C tones and the frequency of the I tone was significant, demonstrating differential trends between the two conditions. The shapes of the curves, however, were not consistent with the predictions. Moreover, the range and magnitude of the I tone effect was a function of the location of I and C tones. Far greater effects on pitch-difference judgments were noted by increasing the difference between S and I tones when the I and C tones were ipsilateral than when they were contralateral to the S tone. While effects of the I tone appeared to have a negligible effect beyond S-25 Hz, the judgments of pitch-difference continued to be influenced by I tones beyond S+25 Hz.

The third prediction requires parallel functions of pitch-difference judgments to be evidenced for each S and C

tone difference. The analysis of variance failed to demonstrate a significant L x I x C interaction, providing some support of the prediction. This is of little consolation, however, considering the failure of the data to satisfy the other predictions. Taken together, there was very little evidence to suggest that the similarity between the S and I tones affected judgments in a manner consistent with interpretations of assimilation of the S tone trace (e.g., Pratt, 1933).

The results of Experiment 1 suggested an alternative to the assumptions of the assimilation of the S tone trace by the presentation of the I tone. When the I stimulus occupied the interval between the S and C tones in that experiment, discrimination was as good as that following a blank retention interval. Hence, if discrimination is a function of the "distance" between the means of S and C tone strength gradients (S' and C'), judgments in these "tonal staircase" conditions should be maintained at levels at least equal to those following the blank retention interval. Difference judgments should drop below the blank conditions in situations which evidenced interference with discrimination; i.e., under contralateral I and C tones or when the I tone is located beyond the S and C tone interval.

This was not supported by the results of the present experiment. Judgments of the difference between S and C tones were maintained above the blank retention intervals for "tonal staircase" conditions. There was some evidence

of "interference" when the I tone was located beyond the S and C tone interval; when C = S+20 and I $\geq$ S+40 Hz, for example. However, judgments of pitch-difference when the I and C tones were contralateral to the S tone never dropped below levels associated with the blank retention interval. It was just these conditions in Experiment 1 which produced evidence of the greatest interference with discrimination. If the effect of interpolating an I tone between the S and C tone frequencies was to maintain the "distance" between them, the functions of pitch-difference judgments should be dependent upon the difference between S and C tones. The nonsignificant L x I x C interaction failed to support this prediction.

In summary, while judgments of the difference between the pitch of two tones were influenced by presenting an I stimulus during the retention interval, the effects were not consistent with predictions of an assimilation hypothesis. Previous interpretations of d' as representing the difference between the means of the S and C tone strength gradients (Wickelgren, 1966, 1969; Massaro, 1970a, c), were shown to be inconsistent with the <u>S</u>'s judgments of the difference between the tones. The judgments of pitch-difference were not consistent with previous results from forced choice recognition or discrimination experiments. There was no clear evidence that pitch-difference could account for the effects of an intervening stimulus upon the discrimination of two tones.

CONCLUSIONS

Four main conclusions may be drawn from the results of these experiments:

1) The presence of an intervening tone substantially influences the discrimination between the S and C tones,

2) The effects of the I tone are dependent upon its relationship to the S and C tones, but the effects are not consistent with an assimilation hypothesis nor predictions of the storage-forgetting model (Massaro, 1970a, c),

3) Judgments of pitch-difference appear to be independent of the performance of Ss in a forced choice discrimination task, and

4) The effects of the I tone in a forced choice discrimination task are most reasonably accounted for by assuming that the I tone affects the S's decision-response criteria.

The arguments supporting these conclusions are rather complex and are best presented by a review of the evidence upon which they are based.

Experiment 1 provided evidence of the effects of presenting an I stimulus during the retention interval of a two-alternative forced choice discrimination task. Previous evidence of interference produced by the interpolated stimulus had been interpreted either as epiphenomena of particular experimental conditions (e.g., Wickelgren, 1969) or retroactive effects upon the memory trace of the standard

tone (Pratt, 1933; Massaro, 1970a, c; Deutsch, 1972b, 1975a, b). The results of Experiment 1 supported the latter conclusion when I and C tones were located in opposite directions from the S tone frequency (contralateral). If the I and C tones were ipsilateral to the S tone, interference was evidenced only when the I tone was placed beyond the interval between S and C tones. Such results are not consistent with assumptions that the similarity between S and I tones affects the degree of retroactive interference produced by the intervening stimulus.

Models of pitch memory which assert that presentation of intervening stimuli actively influences the memorial trace of the S tone (e.g., Lauenstein, 1932; Pratt, 1933; Massaro, 1970a, c; Deutsch, 1972b, 1975b) have led to conclusions that effects of the similarity between S and I tones are a function of a "shift" in the S tone trace. That is, the S tone trace is assumed to be assimilated by the I tone frequency (Lauenstein, 1932; Pratt, 1933) or decay is retarded for a portion of the S tone trace as a function of the similarity ('overlap') between strength gradients of the S and I tones (e.g., Deutsch, 1972b). In addition, the TSD statistic d' (Green & Swets, 1966) usually has been assumed to be related to the difference between means of the strength gradients for S and C tones (Wickelgren, 1966, 1969; Massaro, 1970a). Thus, the effects of the similarity between S and I tones upon d' may be interpreted as representing the 'shift' in the memory trace of the S tone

predicted by assimilation-type models.

It was argued that, should variations in d' represent changes in the mean of the S tone trace due to assimilation by the intervening stimulus, judgments of pitch-difference should provide substantiating evidence of the effect. Moreover, if "same-different" judgments are formed on the basis of pitch-difference, judgments of the difference between S and C tones should evidence functions similar to those from the discrimination task. The results of Experiment 2, while evidencing effects of the similarity between S and I tones, were not consistent with predictions arising from the assimilation-type models nor were the functions of pitch-difference judgments similar to those of d' within a two-alternative forced choice discrimination task.

When pitch-difference judgments were formed under conditions of ipsilateral I and C tones, evidence of a reduction in the difference between S and C tones as a function of the similarity between S and I tones was obtained. When the I and C tones were contralateral to the S tone, there was very little evidence that the S tone trace was "assimilated" by the I tone. Interestingly, judgments of the difference between distinct S and C tones were nearly always augmented by the presence of any intervening stimulus; results which clearly were inconsistent with evidence from discrimination tasks.

It was concluded that the evidence of Experiment 2 provided no support for the assumption that <u>Ss</u> employ pitch-

difference as the mechanism to distinguish S and C tones as "same" or "different." In addition, interpretations of d' as representing the difference between memorial traces of S and C tones were brought into question by the results of Experiment 2. The ability to discriminate between the pitch of two tones, however, is systematically related to the physical difference between them. Effects upon discrimination which are related to the nature of intervening stimuli have been well documented (Lauenstein, 1932; Pratt, 1933; Massaro, 1970a, c; Deutsch, 1972a, b, 1973, 1975a, b; J. Siegel, 1974). The results of Experiment 2 suggest that they are not retroactive effects upon the S tone memory trace.

These effects may be accommodated by assuming that the _S_ employs some aspect other than pitch-difference to discriminate between the S and C tones. Wickelgren (1969) has suggested that "familiarity" is the dimension upon which discrimination is based. It was argued earlier that his conceptions of familiarity do not necessarily exclude properties of a pitch dimension. Deutsch (1972b, 1975) has proposed a model which incorporates a temporal-sequential dimension similiar to familiarity, as well as a pitch-frequency dimension in the discrimination process. In the storage-forgetting model (Massaro, 1970a, b, c), discrimination is based upon aspects of a unidimensional pitch-frequency dimension.

In all of these proposals, the presentation of the S

tone is assumed to establish a strength gradient along an ordered dimension related to the frequency of the tone. When the C tone is presented, the _S_ is assumed to sample from the S tone trace corresponding to the perception of the C tone pitch. In each of these models, discrimination is assumed to follow assumptions of TSD. That is, discrimination is related to the character of the sampled tone _relative to some criterion associated with accepting the C and S tones as having equivalent pitch_. Rather than assuming that the intervening stimulus alters the memory trace of the S tone, it is more plausible that the I tone affects discrimination by altering the _S_'s decision-response criterion.

Discrimination following a retention interval filled with an intervening stimulus is reduced, relative to the blank retention interval, because of changes in the _S_'s response-decision criterion. This criterion is assumed to vary with the similarity between S and I tones. In particular, as the difference between S and I tones increases, the _S_ adopts a more strict criterion for accepting _and reporting_ the S and C tones as "different." Stated within the context of TSD, the likelihood-ratio criterion governing the decision process is affected by the similarity between S and I tones. Within models of pitch memory, a greater degree of activation of the "familiarity representative" (Wickelgren, 1969), or, equivalently, the relative memory strength (Massaro, 1970a; Deutsch, 1972b) of

the sampled S tone trace is required before judgments of "different" will be given by the _S_.

"Interference" produced by the intervening tones is assumed to be a curvilinear function of the similarity between S and I tones, and symmetric about the S tone frequency. That is, as the difference between the S and I tones increases, a more strict decision-response criterion is established by the _S_ until the S and I tones are "distinct." For distinctive (i.e., low similarity) S and I tones, the decision-response criterion approximates that for the blank retention interval. The paradoxical lack of interference produced in the "tonal staircase" conditions of ipsilateral I and C tones is accommodated by assumptions regarding the response strategies available to the _S_.

While discrimination judgments may usually be formed on the basis of "memory strength," it is difficult to imagine that _S_s employ that process in conditions of a "tonal staircase" arrangment of tones. This arrangement of tones is quite distinctive, and the relationship between the S and C tones is obvious to the listener. The _S_s in Experiment 1 typically reported that discrimination was easiest under these conditions. While they reported they were trying to "ignore" the I stimulus, virtually all _S_s related their judgments under the "tonal staircase" conditions to the relationship between the three tones. Thus, it appears that the process of discrimination is dependent upon the nature of the information available to the _S_ within the stimulus

complex (Siegel, 1974). If the difference between S and C tones is easily extrapolated from relations among the stimuli, discrimination is likely to be based upon those. In the absence of more obvious relationships, such strategies likely are abandoned and discrimination based upon the memory trace of the S tone.

It is difficult to develop unequivocal evidence that "interference" is produced by shifts in the S's decision-response criterion. First, discrimination involves not only discriminability of the stimuli but also response discriminability, or "the extent to which a listenser can discriminate the correctness of his own responses to the information source [i.e., presented stimuli]" (Pollack, 1964, p 449). Second, the decision-response process in recognition and discrimination is affected by variables which are only partially under the control of the experimenter (Kintsch, 1970). These include factors which have been viewed traditionally as influencing "response bias," as well as those which influence the "imperfect" observer; i.e., perceptual and memorial inputs to the decision system (Pollack, 1964; Wickelgren, 1969).

Evidence of criterial shifts may be gleaned from the analysis of errors of discrimination.[7] It should be noted

---

[7]These measures are frequently identified as indicies of response bias. "This useage is unfortunate because neither 'response' nor 'bias' serves to distinguish the mechanisms assumed in threshold theories from those assumed in detection theories" (Green & Swets, 1966, p 409).

that these data are not free from effects of other variables. On the other hand it is not clear that any measure of performance, including TSD statistics, may be "uncontaminated" (cf., Banks, 1970; Lockhart & Murdock, 1970). Armed with this caveat, what do the data suggest?

Massaro's (1970a, Exp II) data indicated that the proportion of errors ("same" responses when $S \neq C$) increased, not only when the S and C tone difference was smaller but in relation to the similarity between S and I tones. As noted earlier, Massaro concluded that Ss "required a much larger perceived difference before they said 'different' with a dissimilar I stimulus [S+90 Hz] than with a similar I stimulus [S+20 Hz]" (p 38). These results are attributed to varying 'response bias' and/or response strategies of the Ss. The intent of this explanation is not clear, but it certainly does not preclude systematic changes in the S's decision-response system. The data of Experiment 1 are consistent with those from Massaro (1970a). The general effect of decreasing the similarity between S and I tones was to increase the proportion of "same" responses when $S \neq C$; i.e., establish more strict criteria of the decision-response system. The I x C interaction apparently is attributed to extra-criterial effects of the "tonal staircase" conditions and 'bias' introduced by the constant location of the I tone. The data provide some support for the hypothesis, however.

Similar interpretations of discrimination "errors" have

been provided in studies by Aiken & Lau (1966), Bindra, et al. (1965) and Angell & Harwood (1899). The latter study showed evidence of a reduction in discrimination as a function of increased periods of retention. Bindra, et al. (1965) noted that assumptions of differential decision criteria accounted for errors of discrimination at two retention intervals. In that study more errors were evidenced at the longer retention interval, but the majority were "false detections" ("different" responses when C = S) for both retention intervals. Aiken & Lau (1966), while showing no effect of retention interval upon correct discrimination, noted a similar pattern of errors. Each of these studies involved blank retention intervals, and it is necessary to consider this factor when interpreting the results.

While "there is no guarantee that the _S_'s criterion remains constant over time" of the retention interval (Kintsch, 1970, p 233), the effects of increasing the retention interval need not be limited to factors of the decision-response process. A decaying memory trace of the S tone would lead to equivalent data. As an example, following presentation of the S tone, the memory trace is assumed to lose strength in an exponential fashion. During presentation of the C tone, that trace is sampled and the "strength" of the sample matched against some fixed criterion. Increased errors of falsely detecting a difference between equivalent S and C tones would be due to less and less of the S tone trace exceeding the strength

criterion of "same" as the retention interval increased. It is possible, however, that changes in the decision-response criterion and decay of the S tone trace may interact to produce decrements in discrimination with increases in the retention interval. For many reasons, not the least of which is the variety of variables left uncontrolled during blank retention intervals (Wickelgren, 1966, 1969; Massaro, 1970a), it is not clear that one or the other alternatives is the correct one.

Jesteadt & Sims (1975) have suggested that "memory variance" in discrimination and detection tasks is best interpreted as variance within the decision-response process. Comparing a variety of detection and discrimination tasks, they conclude:

> Memory variance is entering into decision processes in the discrimination task but not in the detection task .... The additional source of variance is not related to a specific signal ensemble but is central in origin. The approach most compatable with TSD is to interpret the memory variance as criterion variance and to assume that the criterion is more stable in detection than discrimination tasks (p 1167).

Results of the present experiments lead to a similar interpretation, but suggest that differential mechanisms are involved in the discrimination of tonal stimuli, depending upon the task demands placed upon the S. While judgments of pitch-difference may be based upon the perceived difference between the stimuli, same-different judgments are not. Either Wickelgren's (1969) hypothesis of "familiarity" or Massaro's (1970a, c) "strength" model may account for the

process of discrimination. Contrary to Wickelgren's (1969) assumptions, similarity between the S and I tones systematically effects discrimination. The nature of this effect is best interpreted in terms of influences upon the decision-response process, rather than the retroactive effects of the I tone upon the memory trace of the S tone as assumed by Massaro (1970a). It is necessary to include the role of "higher order" factors when discrimination may be based upon relational properties within the stimulus complex.

REFERENCES

Aaronson, D. Temporal factors in perception and short-term memory. Psychological Bulletin, 1967, 67, 130-144.

Aiken, E.G. & Lau, A.W. Memory for the pitch of a tone. Perception and Psychophysics, 1966, 1, 231-233.

Andreas, B.G. Experimental Psychology. New York: John Wiley & Sons, 1960.

Angell, F. & Harwood, H. Experiments on discrimination of clangs for different intervals of time. American Journal of Psychology, 1899, 11, 67-79.

Atkinson, R.C. & Shriffin, R.M. Human memory: A proposed system and its control processes. In K.W. Spence & J.W. Spence (Eds) The Psychology of Learning and Motivation: Advances in Research and Theory, Vol 2. New York: Academic Press, 1968.

Bachem, A. Time factors and absolute pitch determination. Journal of the Acoustical Society of America, 1954, 26, 751-753.

Banks, W.P. Signal detection theory and human memory. Psychological Bulletin, 1970, 74, 81-99.

Békésy, G. von The variation of phase along the basalar membrane with sinosoidal vibration. Journal of the Acoustical Society of America, 1947, 19, 452-460.

Bernbach, H.A. The effect of labels in short-term memory for colors with nursery school children. *Psychonomic Science*, 1967, *7*, 149-150.

Bernbach, H.A. A multiple-copy model of postperceptual memory. In D.A. Norman (Ed) *Models of Human Memory*. New York: Academic Press, 1970.

Bindra, D., Williams, J.A. & Wise, J.S. Judgments of sameness and difference: Experiments on decision time. *Science*, 1965, *150*, 1625-1627.

Broadbent, D.E. Flow of information through the organism. *Journal of Verbal Learning and Verbal Behavior*, 1963, *2*, 34-39.

Brown, J.A. Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology*, 1958, *10*, 12-21.

Cudahy, E. & Leshowitz, B. Effects of a contralateral interference tone on auditory recognition. *Perception and Psychophysics*, 1974, *15*, 16-20.

Davis, D.J. Flexibility and power in comparisons among means. *Psychological Bulletin*, 1969, *71*, 411-444.

Dember, W.N. *Psychology of Perception*. New York: Holt, Rinehart & Winston, 1965.

Deutsch, D. Tones and numbers: Specificity of interference in immediate memory. *Science*, 1970, *168*, 1604-1608.

Deutsch, D. Mapping of interactions in the pitch memory store. _Science_, 1972a, _175_, 1020-1022.

Deutsch, D. Effects of repetition of standard and comparison tones on recognition memory for pitch. _Journal of Experimental Psychology_, 1972b, _93_, 156-162.

Deutsch, D. Interference in memory between tones adjacent in the musical scale. _Journal of Experimental Psychology_, 1973a, _100_, 228-231.

Deutsch, D. Octave generalization of specific interference effects in memory for tonal pitch. _Perception and Psychophysics_, 1973b, _13_, 271-272.

Deutsch, D. Facilitation by repetition in recognition for tonal pitch. _Memory and Cognition_, 1975a, _3_, 263-266.

Deutsch, D. Auditory memory. _Canadian Journal of Psychology_, 1975b, _29_, 87-105.

Deutsch, D. & Feroe, J. Disinhibition in pitch memory. _Perception and Psychophysics_, 1975, _17_, 320-324.

Deutsch, D. & Roll, P.L. Error patterns in delayed pitch comparision as a function of relational context. _Journal of Experimental Psychology_, 1974, _103_, 1027-1034.

Harris, J.D. The decline of pitch discrimination with time. _Journal of Experimental Psychology_, 1952, _43_, 96-99.

Leshowitz, B. & Green, D.M. Comments on "Absolute Judgment and Paired Associate Learning: Kissing Cousins or Identical Twins" by J.A. Siegel and W. Siegel. _Psychological Bulletin_, 1974, _81_, 177-179.

Irwin, C.C. A study of differential pitch sensitivity relative to auditory threshold. *Journal of Experimental Psychology*, 1937, *21*, 642-652.

Jesteadt, W. & Sims, S.L. Decision process in frequency discrimination. *Journal of the Acoustical Society of America*, 1975, *57*, 1161-1168.

Köhler, W. Zur Theorie des Sukzessivvergleichs und der Zeitfehler. *Psychologische Forschung*, 1923, *4*, 115-175. (cited in Köhler, 1938)

Köhler, W. *The Place of Value in a World of Facts*. New York: Liverwright Publishing Company, 1938.

Kintsch, W. *Learning, memory and conceptual processes*. New York: John Wiley & Sons, 1970.

Lauenstein, O. Ansatz zu einer physiologischen Theoris des Vergleichs und der Zeitfehler. *Psychologische Forschung*, 1932, *17*, 130-177. (cited in Pratt, 1933)

Leshowitz, B. & Cudahy, E. Frequency discrimination in the presence of another tone. *Journal of the Acoustical Society of America*, 1973, *54*, 882-887.

Leshowitz, B. & Hanzi, R. Serial position effects for tonal stimuli. *Memory and Cognition*, 1974, *2*, 112-116.

Leshowitz, B. & Wightman, F.L. On-frequency masking with continuous sinusoids. *Journal of the Acoustical Society of America*, 1971, *49*, 1180-1190.

Lockhart, R.S. & Murdock, B.B., Jr. Memory and the theory of signal detection. _Psychological Bulletin_, 1970, _74_, 100-109.

Massaro, D.M. Retroactive interference in short-term recognition memory for pitch. _Journal of Experimental Psychology_, 1970a, _83_, 32-39.

Massaro, D.M. Forgetting: Interference or decay? _Journal of Experimental Psychology_, 1970b, _83_, 238-242.

Massaro, D.M. Consolidation and interference in the perceptual memory system. _Perception and Psychophysics_, 1970c, _7_, 153-156.

Massaro, D.M. Preperceptual auditory images. _Journal of Experimental Psychology_, 1970d, _85_, 411-417.

Massaro, D.M. Effect of masking tone on preperceptual auditory images. _Journal of Experimental Psychology_, 1971, _87_, 146-148.

Massaro, D.M. Preperceptual images, processing time and perceptual units in auditory perception. _Psychological Review_, 1972a, _79_, 124-145.

Massaro, D.M. Stimulus information vs processing time in auditory pattern recognition. _Perception and Psychophysics_, 1972b, _12_, 50-66.

Massaro, D.W. & Kahn, B.J. Effects of central processing on auditory recognition. _Journal of Experimental Psychology_, 1973, _97_, 51-58.

Melton, A.W. Implications of short-term memory for a general theory of memory. _Journal of Verbal Learning and Verbal Behavior_, 1963, _2_, 1-21.

McGeoch, J.A. Forgetting and the laws of disuse. _Psychological Review_, 1932, _32_, 352-370.

Moss, S.M., Myers, J.L. & Filmore, T. Short-term recognition memory for tones. _Perception and Psychophysics_, 1970, _7_, 369-373.

Murdock, B.B. Jr. Short-term memory. In G.H. Bower (Ed), _The Psychology of Learning and Motivation: Advances in Research and Theory_, Vol 5. New York: Academic Press, 1972

Norman, D.A. & Rumelhart, D.E. A system for perception and memory. In D.A. Norman (Ed), _Models of Human Memory_. New York: Academic Press, 1970.

Norman, D.A. & Wickelgren, W.A. Short-term retention memory for single digits and pairs of digits. _Journal of Experimental Psychology_, 1965, _70_, 479-489.

Peterson, L.R. & Peterson, M.J. Short-term retention of individual items. _Journal of Experimental Psychology_, 1959, _58_, 193-198.

Pratt, C.C. The time-error in psychophysical judgments. _American Journal of Psychology_, 1933, _45_, 292-297.

Pollack, I. Identification of elementary auditory displays and the method of recognition memory. In J.A. Swets (Ed) _Signal Detection and Recognition Memory for Human Observers: Contemporary Readings_. New York: John Wiley

& Sons, 1964.

Postman, L. The time-error in auditory perception. _American Journal of Psychology_, 1946, _59_, 193-219.

Schouten, J.F., Ritsma, R. & Cardozo, B. Pitch as residue. _Journal of the Acoustical Society of America_, 1962, _34_, 1418-1424.

Siegel, J.A. The nature of absolute pitch. In I.E. Gordon (Ed), _Studies in the Psychology of Music_. Iowa City: University of Iowa, 1972.

Siegel, J.A. Sensory and verbal coding strategies in subjects with absolute pitch. _Journal of Experimental Psychology_, 1974, _103_, 37-44.

Siegel, J.A. & Siegel, W. Absolute judgment and paired associate learning: Kissing cousins or identical twins. _Psychological Review_, 1972, _79_, 300-316.

Siegel, W. Memory effects in the method of absolute judgment. _Journal of Experimental Psychology_, 1972, _94_, 121-131.

Sperling, G. & Speelman, R.G. Acoustic similarity and auditory short-term memory experiment and a model. In D.A. Norman (Ed), _Models of Human Memory_. New York: Academic Press, 1970.

Thurlow, W.R. Audition. In J.W. Kling & L.A. Riggs (Eds), _Woodworth's & Schlosberg's Experimental Psychology_, 3rd Edition. New York: Holt Rhinehart & Winston, 1971

Underwood, B.J. Interference and forgetting. _Psychological Review_, 1957, _64_, 49-60.

Underwood, B.J. _Experimental Psychology_, 2nd Edition. New York: Appleton Century Crofts, 1966.

Wever, E.G. & Bray, C.W. Action currents in the auditory nerve in response to acoustic stimulation. _Proceedings of the National Academy of Science_, 1930, _16_, 344-350.

Whipple, G.M. An analytic study of the memory image and the process of judgment in the discrimination of clangs and tones. _American Journal of Psychology_, 1901, _12_, 409-457.

Wickelgren, W.A. Consolidation and retroactive interference in short-term recognition memory for pitch. _Journal of Experimental Psychology_, 1966, _72_, 250-259.

Wickelgren, W.A. Associative strength theory of recognition memory for pitch. _Journal of Mathematical Psychology_, 1969, _6_, 13-61.

Wightman, F.L. Pitch and stimulus fine structure. _Journal of the Acoustical Society of America_, 1973, _54_, 397-406.

Wightman, F.L. & Green, D.M. The perception of pitch. _American Scientist_, 1974, _62_, 208-215.

Wolfe, H.K. Untersuchungen über das Tongedächtniss. _Philosophische Studien_, 1866, _3_, 534-574. (cited in Angell & Harwood, 1899)